PB2001-100138

Technical Report Documentation Page

1. Report No.	2.	3. Recipient's Catalog No.
4. Title and Subtitle NCHRP REPORT 350 TEST 3-11 OF THE WASHINGTON 3-STRAND CABLE BARRIER WITH NEW YORK CABLE TERMINAL		5. Report Date March 2000 6. Performing Organization Code
7. Author(s) D. Lance Bullard, Jr., Wanda L. Menges, C. Eugene Buth, and Sandra K. Schoeneman		8. Performing Organization Report No. 404211-8
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH61-97-C-00039
12. Sponsoring Agency Name and Address Federal Highway Administration U. S. Department of Transportation 400 Seventh Street, S. W. Washington, D. C. 20590		13. Type of Report and Period Covered Draft Test Report July 1997 - March 2000 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with Federal Highway Administration (FHWA)
Research Study Title: Assessment of Existing Roadside Safety Hardware - II
Contracting Officer's Technical Representative (COTR): Charles F. McDevitt - HSR-20

16. Abstract

The Federal Highway Administration (FHWA) initiated a research project to assess the performance of several highway safety appurtenances in accordance with the guidelines presented in National Cooperative Highway Research Program *(NCHRP) Report 350.* The State of Washington's 3-strand cable barrier was one of the installations selected for testing.

Testing was begun on the Washington 3-strand cable barrier in March 1996 by the Washington Department of Transportation. A single test, *NCHRP Report 350* test designation 3-10, the 820 kg small car length-of-need test was performed in March 1996. The cable barrier performed acceptably in the test.

The FHWA and the state of Washington sought to complete the length-of-need testing and evaluation of the Washington 3-strand cable barrier. Therefore, *NCHRP Report 350* test designation 3-11, the 2000 kg pickup truck length-of-need test was performed and is reported herein. *NCHRP Report 350* test designation 3-11 requires a 2000-kg pickup truck to impact the length-of need (LON) section of the barrier at a nominal speed and angle of 100 km/h and 25 degrees, respectively. A 145 m long test installation of Washington 3-strand cable barrier was constructed with New York cable terminals on each end, as specified by the FHWA. Details of the installation and results of the full-scale crash test are presented herein. The Washington 3-strand cable barrier with New York cable terminals performed acceptably for *NCHRP Report 350* test designation 3-11.

17. Key Words Guardrail, median barrier, cable barrier, terminal, crash testing, roadside safety	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72)

ATTENTION

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

NOTE: Volumes greater than 1000 l shall be shown in m^3.

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C+32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PB2001-100138

INTRODUCTION

PROBLEM

The primary purpose of longitudinal safety barriers, such as cable barriers, is to prevent errant vehicles that depart the roadway from 1) entering opposing travel lanes, 2) encountering terrain features that may not be safely traversable by a motor-vehicle and/or 3) to shield fixed roadside hazards. When installation of a highway safety barrier becomes warranted, the barrier should perform by safely containing and/or redirecting the errant vehicle away from the hazard. Performance of the safety barrier can be evaluated through a series of full-scale crash tests in accordance with guidelines presented in National Cooperative Highway Research Program (NCHRP) Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*.(1)

BACKGROUND

On July 25, 1997, the Federal Highway Administration (FHWA) mandated that new construction on the National Highway System (NHS) must use *NCHRP Report 350* approved longitudinal barriers by October 1,1998. Under a current contract with Texas Transportation Institute (TTI), FHWA has authorized testing for several guardrails, transitions, and end treatments. Under this contract, officials at FHWA decided the Washington cable barrier should be tested in accordance to the guidelines presented in *NCHRP Report 350* for test level three (TL-3) performance.

In 1996, the Washington 3-strand cable barrier was subjected to *NCHRP Report 350* test designation 3-10.(2) The test involved an 820-kg passenger car impacting the barrier at post 12. The impact speed was 99.7 km/h and the vehicle impact angle was 20.4 degrees relative to the barrier. The barrier performed by redirecting and containing the vehicle. The two rear mounted cables went under the vehicle and the vehicle became entrapped between the front and rear cables. The cable barrier met all evaluation criteria set forth for *NCHRP Report 350* test designation 3-10.

Under the current contract, *NCHRP Report 350* test designation 3-34 was performed on the New York cable terminal.(3) This test involved an 820-kg passenger vehicle impacting the terminal at the critical impact point (CIP) at a speed and angle of 99.3 km/h and 14.7 degrees, respectively. FHWA and TTI determined the CIP was the right front corner of the bumper of the vehicle impacting the cables in the downward sloping portion to the anchor. The New York cable terminal allowed the vehicle to gate through the end of the installation with minimal damage to the vehicle. The New York cable terminal performed acceptably as a gating terminal according to criteria specified in *NCHRP Report 350* test designation 3-34.

Officials at FHWA decided the installation constructed for the test of the Washington 3-strand cable barrier should incorporate the New York cable terminal.

OBJECTIVE

The objective of the test reported herein was to determine if the Washington 3-strand cable barrier anchored with New York cable terminal ends would perform acceptably according to evaluation criteria set forth in *NCHRP Report 350* for test level three longitudinal barriers. The test performed (test designation 3-11) involves a 2000-kg pickup truck impacting the LON of the barrier at a nominal speed and angle of 100 km/h and 25 degrees, respectively. The test is intended to evaluate the structural strength of the barrier and its ability to contain and redirect the 2000-kg pickup truck.

A 145 m long test installation of Washington 3-strand cable barrier was constructed at TTI's Proving Ground. The installation was constructed with the New York cable terminal on each end. The height of the guardrail to the top of the upper cable was 770 mm. The LON of the barrier was constructed in accordance with Washington State Department of Transportation standard drawings with modifications (New York cable terminals) specified by FHWA. Posts were installed in drilled holes and backfilled with *NCHRP Report 350* standard soil.

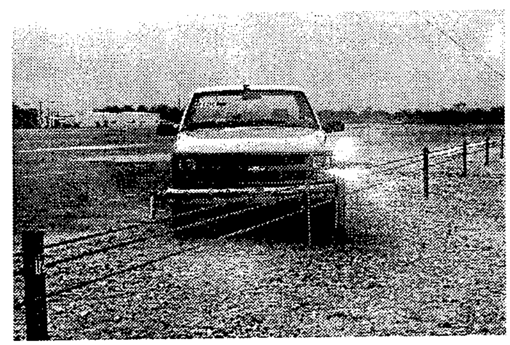
Details of the installation and results of the full-scale crash test are presented herein. The Washington 3-strand cable barrier with New York cable terminals performed acceptably according to the criteria presented in *NCHRP Report 350* for test designation 3-11.

TECHNICAL DISCUSSION

TEST PARAMETERS

Test Facility

The test facilities at the Texas Transportation Institute's Proving Ground consist of an 809-hectare complex of research and training facilities situated 16 km northwest of the main campus of Texas A&M University. The site, formerly an Air Force Base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for placing of the Washington 3-strand cable barriers is along a wide expanse of concrete aprons which were originally used as parking aprons for military aircraft. These aprons consist of unreinforced jointed concrete pavement in 3.8 m by 4.6 m blocks (as shown in the adjacent photo) nominally 203 to 305 mm deep. The aprons and runways are about 50 years old and the joints have some displacement, but are otherwise flat and level. The barrier was installed in Georgetown crushed limestone (*NCHRP Report 350* standard soil).



Test Article – Design and Construction

A 145 m long 3-strand cable barrier was constructed for full-scale crash testing. The length-of-need was constructed using details of the Washington 3-strand cable barrier (figure 1) and the terminals used details of the New York Cable Terminal (figure 2). The installation was constructed on level terrain and the posts were installed in *NCHRP Report 350* standard soil. Installation height of the top cable was 770 mm from the ground surface to the top of the upper cable. The posts were S75 x 8.5 x 1.6 m and spaced 5.0 m on-center. The three cables were each 19 mm in diameter, spaced 120 mm apart and manufactured in accordance with American Association of State Highway Transportation Officials (AASHTO) M-30, Type I, Class A coating. All cable ends were fitted with open end wedge type cable socket fittings. Each cable end was attached to a standard turnbuckle assembly and bolted to a breakaway anchor angle and anchored rigidly to a concrete footing. Additionally, the last post on each end of the installation was anchored in a concrete footing and made frangible by a slip base connection. The concrete footing for the cable anchor terminal, shown in figure 2, and the last post (each integral unit) were constructed in two units that mated together with a tongue and groove. Each unit measured 660 mm by 1005 mm at the top and tapered to 725 mm by 1150 mm at the bottom. The height of the footing along the centerline of the post and terminal was 990 mm. The tops of the

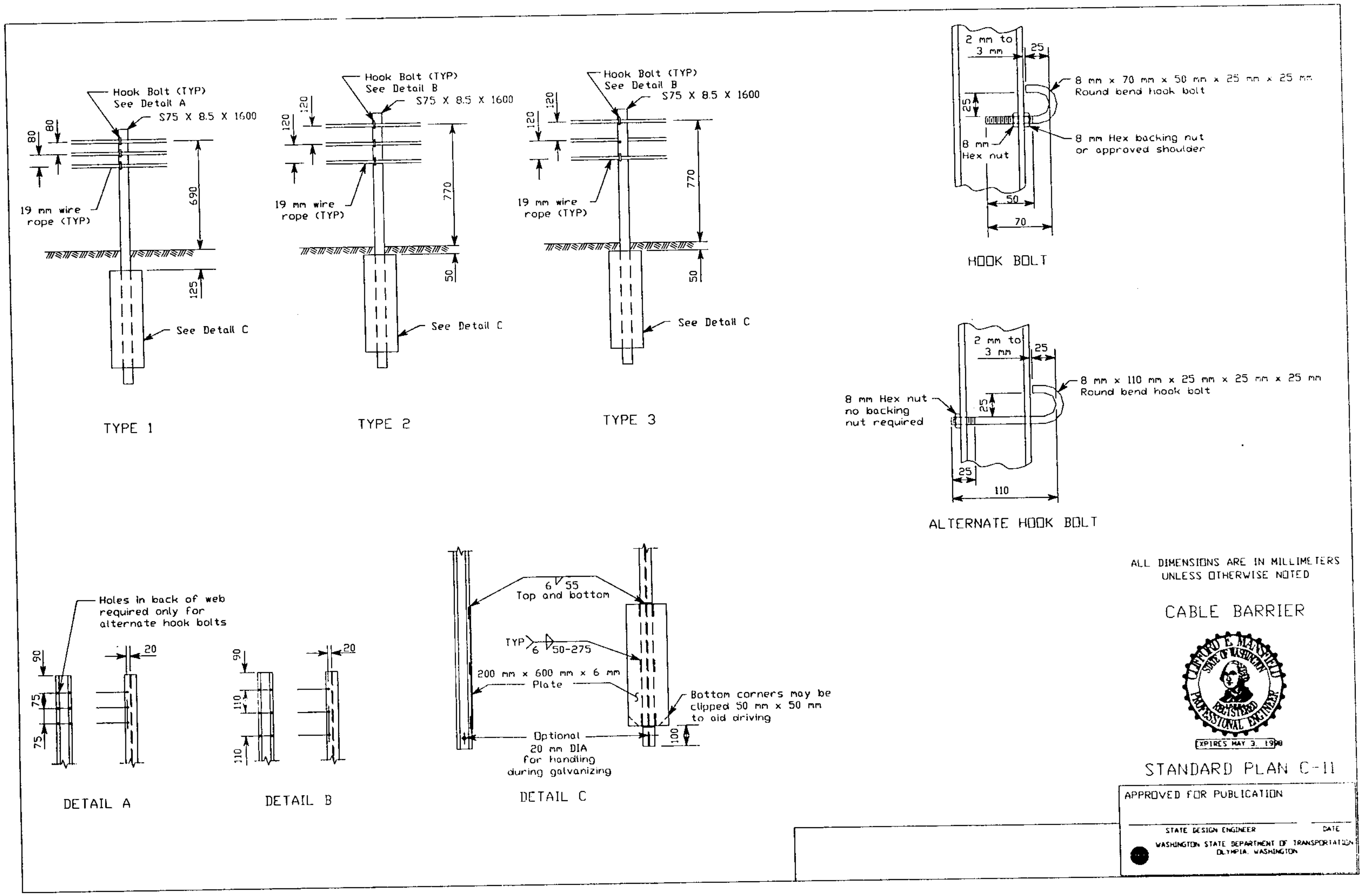
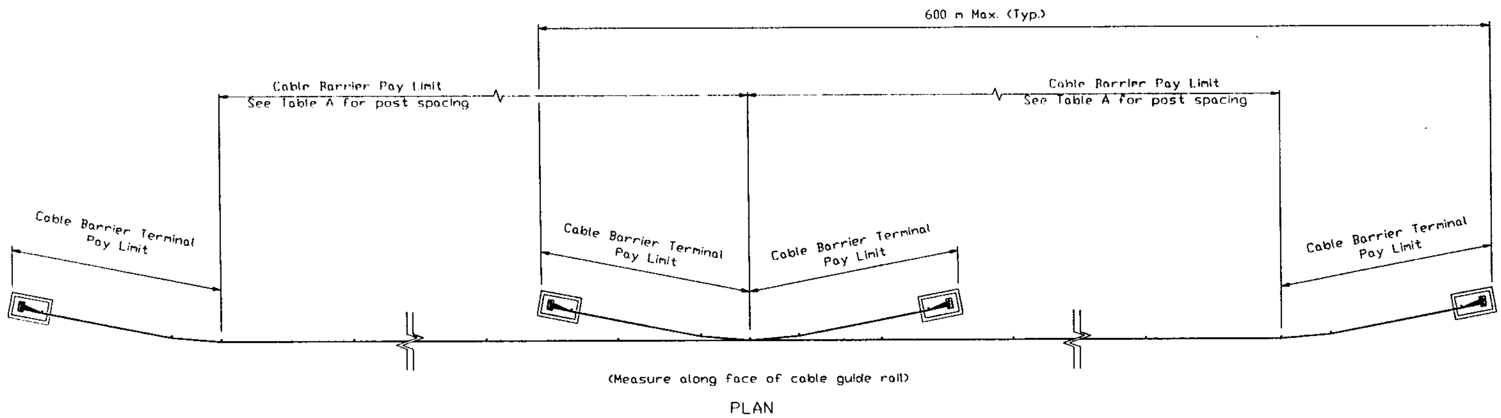


Figure 1. Details of the Washington 3-strand cable barrier for test 404211-8.

NOTES

1. When installed in front of slopes steeper than 1:6 distance between posts and slope break point shall be 300 mm Min.
2. Where barrier is parallel to the edge of the travelled way, every sixth post shall have a reflector. Reflectors shall be white when installed on the right side of traffic, and yellow when installed on the left side of traffic.

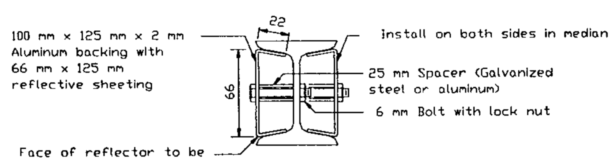


PLAN

ALL DIMENSIONS ARE IN MILLIMETERS UNLESS OTHERWISE NOTED

TABLE A

Curve Radius	Post Spacing
210 m or more	5.0 m
209 m to 66 m	3.5 m
65 m to 33 m	1.8 m
Less Than 33 m	Use Not Recommended



REFLECTOR
(See Note 2)

CABLE BARRIER PLACEMENT

DATE	REVISION	BY
1/99	Noted maximum length on Plan View	RG

APPROVED FOR PUBLICATION

DEPUTY STATE DESIGN ENGINEER   DATE

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION
OLYMPIA, WASHINGTON

Figure 1. Details of the Washington 3-strand cable barrier for test 404211-8 (continued).

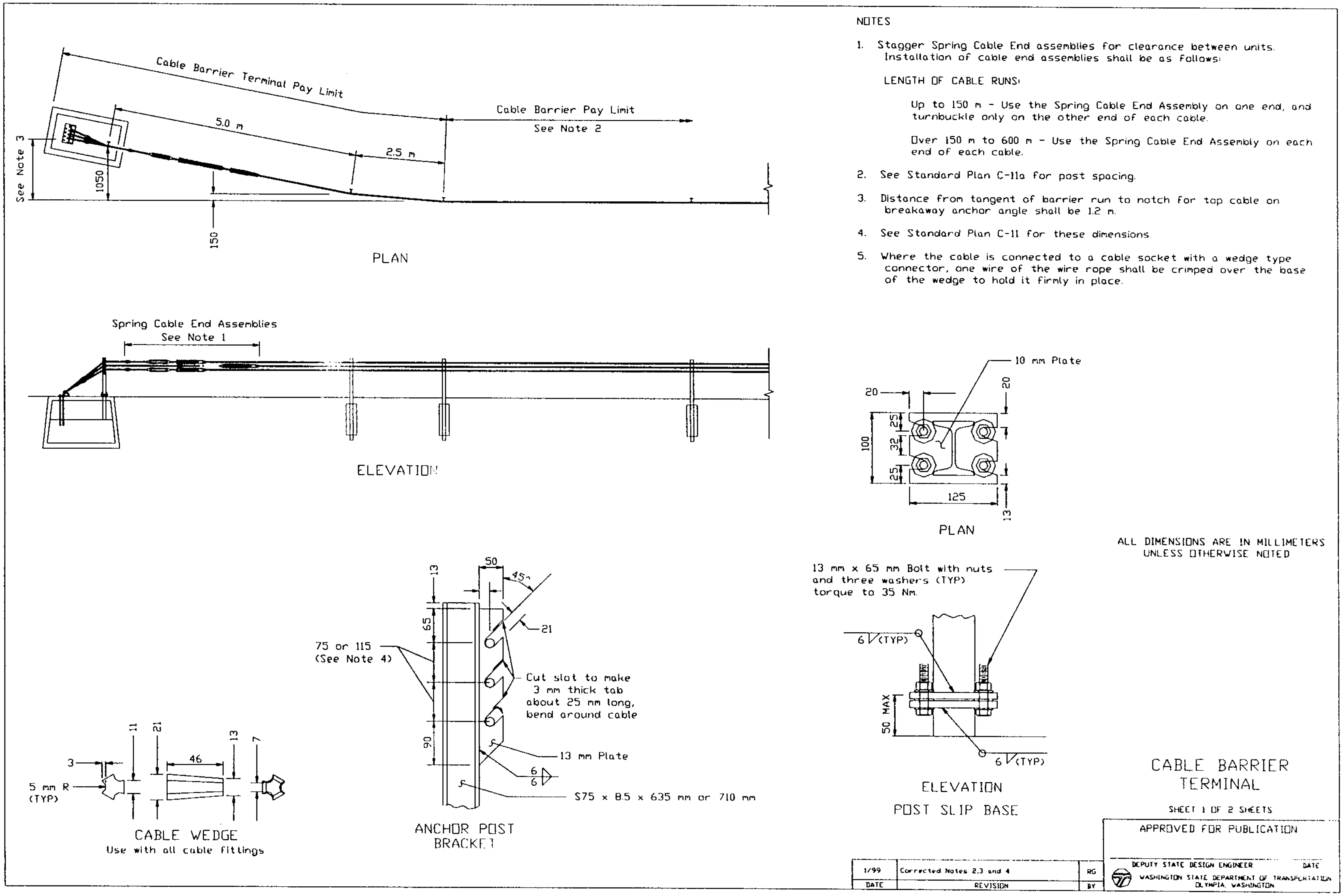


Figure 1. Details of the Washington 3-strand cable barrier for test 404211-8 (continued).

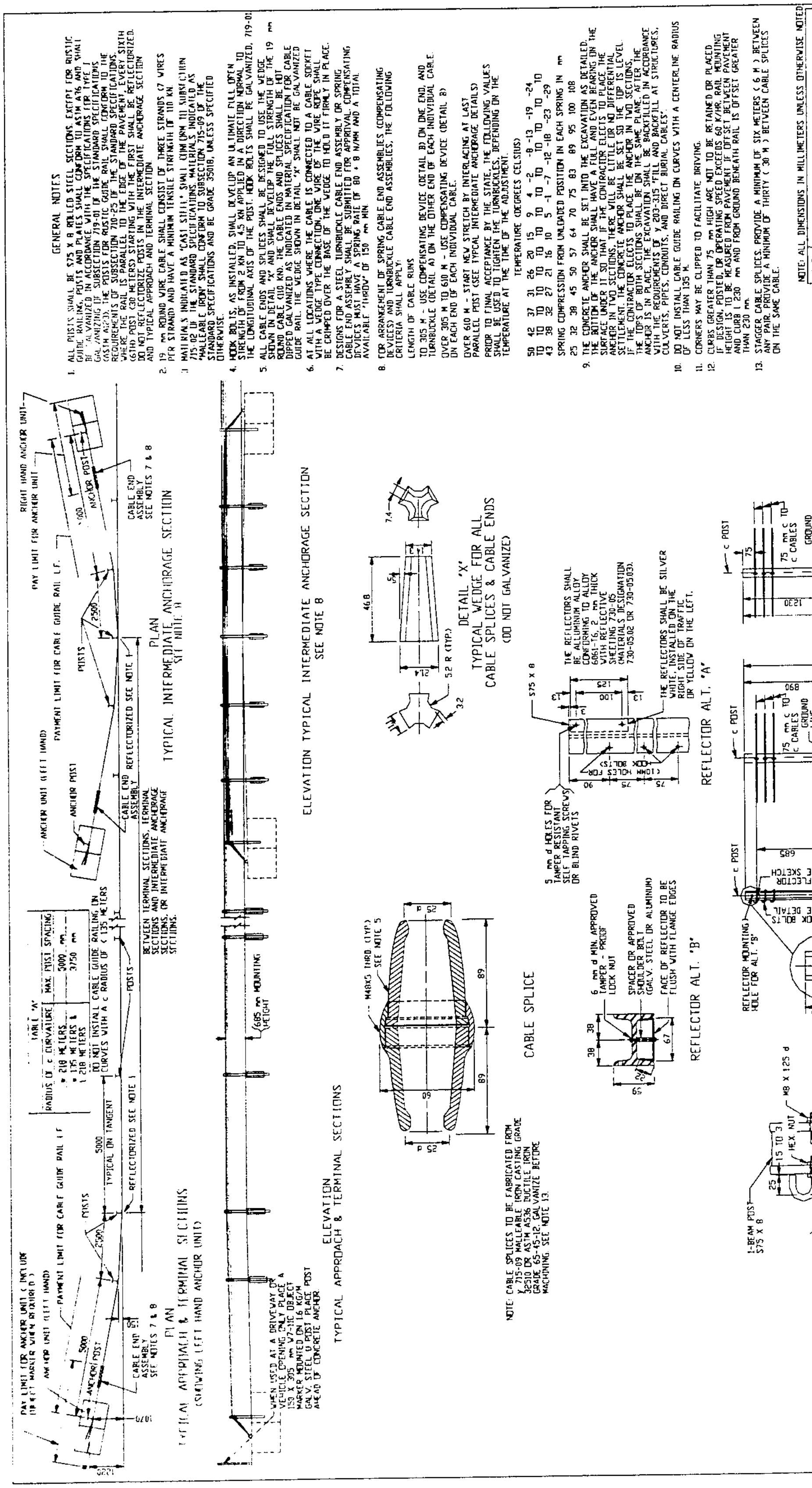


Figure 2. Details of the New York cable terminal used for test 404211-8.

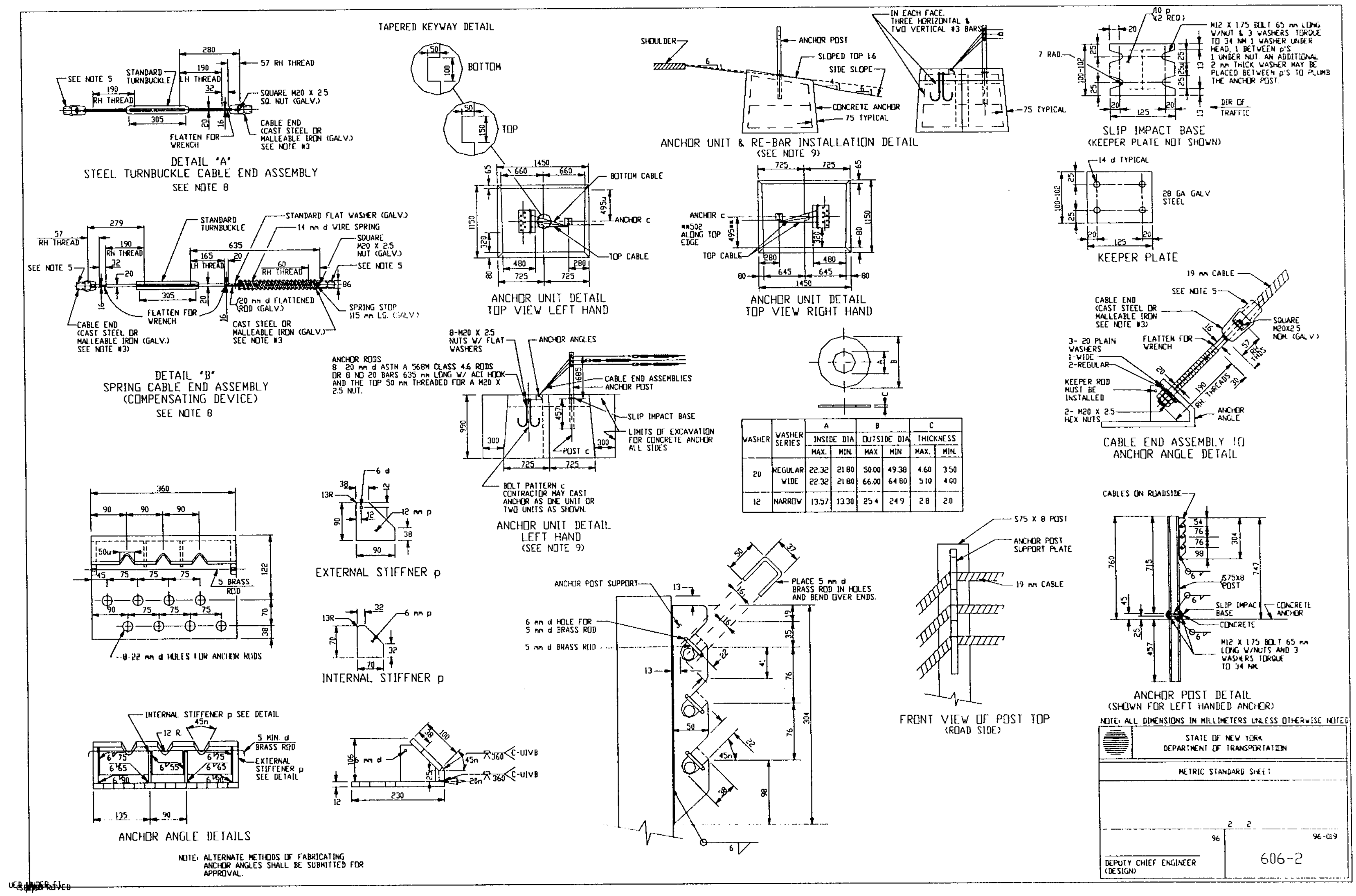


Figure 2. Details of the New York cable terminal used for test 404211-8 (continued).

terminal units were constructed on a 6:1 slope. The units were connected together by an integral key way measuring 50 mm by 100 mm at the bottom and 50 mm by 150 mm at the top. The last post flared back from the tangent a total distance of 1200 mm over a total distance of 7500 mm to the first post. On one end of each of the cables, adjacent to the standard turnbuckle, a spring cable end assembly was attached. The spring cable assembly consisted of the standard turnbuckle with 305 mm of take-up, a 20-mm diameter threaded steel rod on each end, and a spring compensating device on one end. The spring compensating device had a spring rate of 80 + 8 N/mm and a total minimum throw of 150 mm minimum. For the temperature conditions present just prior to the time of the crash test, the spring compensator was compressed 54 mm. Construction details are shown in figures 1 and 2. A layout of the test installation is shown in figure 3. Photographs of the test installation are shown in figure 4.

Test Conditions

According to *NCHRP Report 350*, two crash tests are required for evaluation of longitudinal barriers to test level three (TL-3):

> ***NCHRP Report 350* test designation 3-10**: An 820-kg passenger car impacting the critical impact point (CIP) in the length of need (LON) of the longitudinal barrier at a nominal speed and angle of 100 km/h and 20 degrees. The purpose of this test is to evaluate the overall performance of the LON section in general, and occupant risks in particular.
>
> ***NCHRP Report 350* test designation 3-11**: A 2000-kg pickup truck impacting the CIP in the LON of the longitudinal barrier at a nominal speed and angle of 100 km/h and 25 degrees. The test is intended to evaluate the strength of the section for containing and redirecting the pickup truck.

The test reported herein corresponds to *NCHRP Report 350* test designation 3-11. The CIP for this test was determined using information contained *NCHRP Report 350* and accordingly was determined to be at post 11.

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented in appendix A.

Evaluation Criteria

The crash test performed was evaluated in accordance with the criteria presented in *NCHRP Report 350*. As stated in *NCHRP Report 350*, "Safety performance of a highway appurtenance cannot be measured directly but can be judged on the basis of three factors: structural adequacy, occupant risk, and vehicle trajectory after collision." Accordingly, the following safety evaluation criteria from table 5.1 of *NCHRP Report 350* were used to evaluate the crash test reported herein:

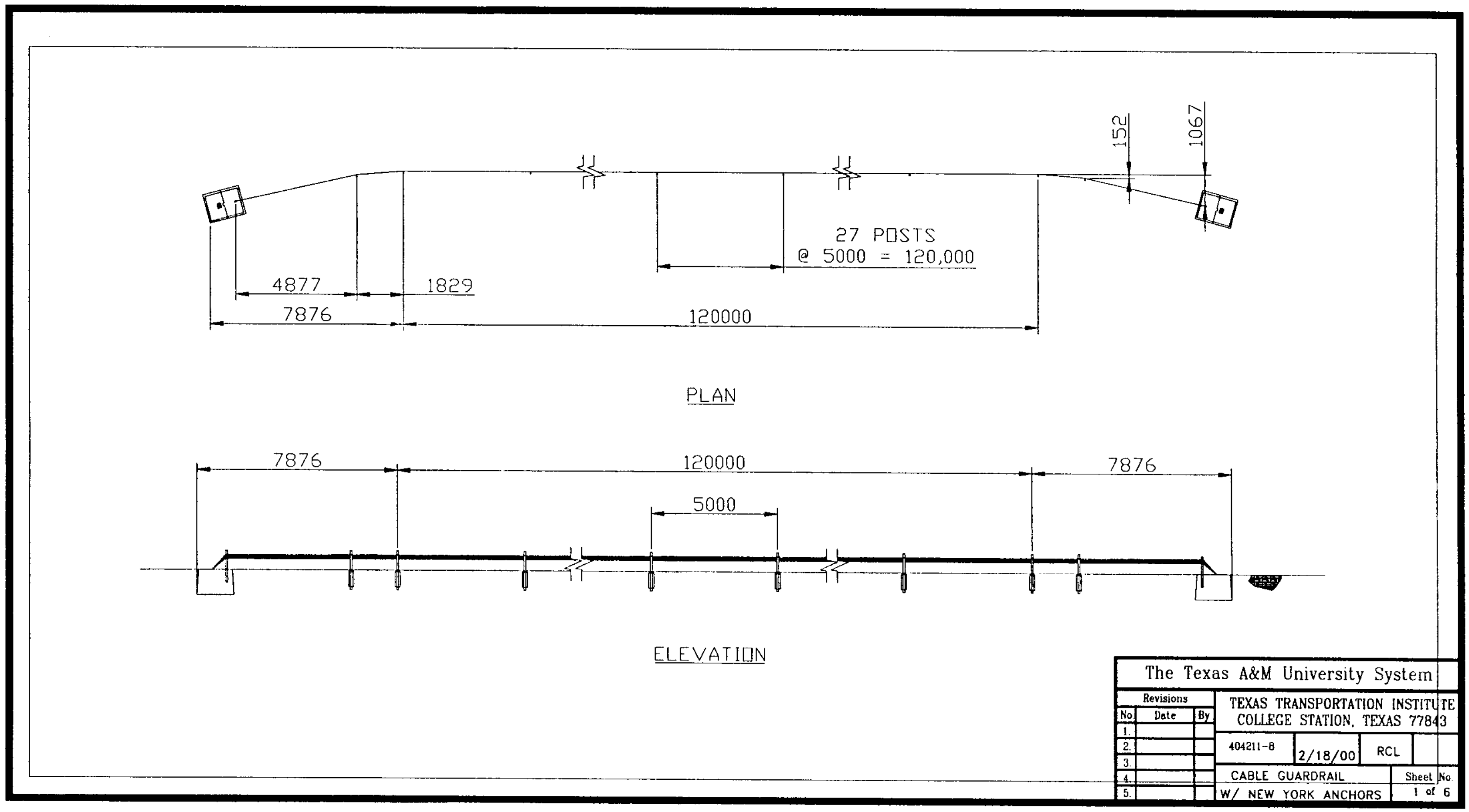


Figure 3. Layout of test installation.

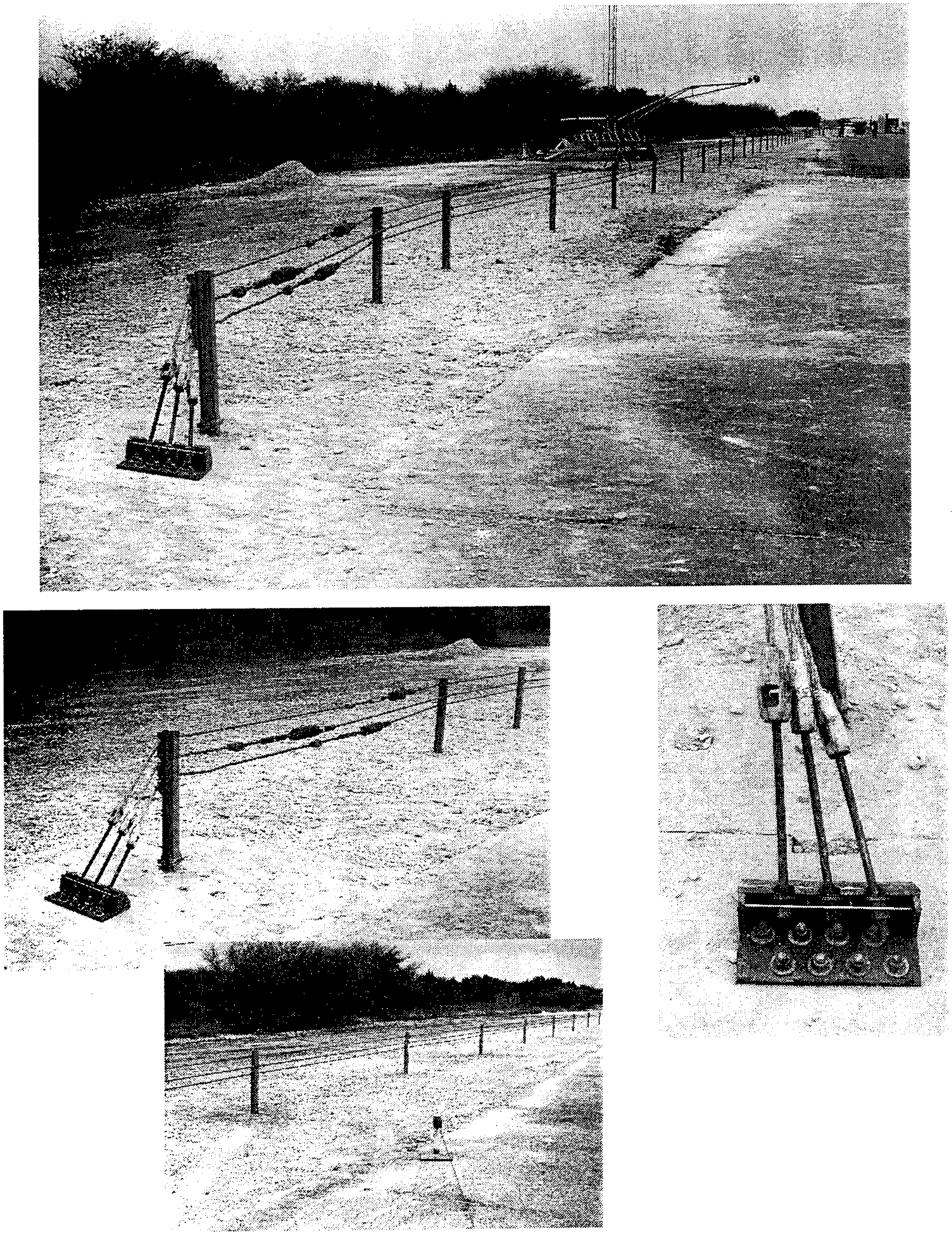


Figure 4. Washington 3-strand cable barrier prior to testing.

- **Structural Adequacy**

  A. *Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*

- **Occupant Risk**

  D. *Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.*

  F. *The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.*

- **Vehicle Trajectory**

  K. *After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*

  L. *The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acc*eleration in the *longitudinal direction should not exceed 20 G's.*

  M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

In a memo entitled: *Action: Identifying Acceptable Highway Safety Features*, FHWA suggests the following supplemental evaluation factors and terminology be used for visual assessment of test results:

PASSENGER COMPARTMENT INTRUSION

1. Windshield Intrusion

a. No windshield contact
b. Windshield contact, no damage
c. Windshield contact, no intrusion
d. Device embedded in windshield, no significant intrusion
e. Complete intrusion into passenger compartment
f. Partial intrusion into passenger compartment

2. Body Panel Intrusion

LOSS OF VEHICLE CONTROL

1. Physical loss of control

2. Loss of windshield visibility

3. Perceived threat to other vehicles

4. Debris on pavement

PHYSICAL THREAT TO WORKERS OR OTHER VEHICLES

1. Harmful debris that could injure workers or others in the area

2. Harmful debris that could injure occupants in other vehicles

VEHICLE AND DEVICE CONDITION

1. Vehicle Damage

a. None
b. Minor scrapes, scratches or dents
c. Significant cosmetic dents
d. Major dents to grill and body panels
e. Major structural damage

2. Windshield Damage

a. None
b. Minor chip or crack
c. Broken, no interference with visibility
d. Broken and shattered, visibility restricted but remained intact
e. Shattered, remained intact but partially dislodged
f. Large portion removed
g. Completely removed

3. Device Damage

a. None
b. Superficial
c. Substantial, but can be straightened
d. Substantial, replacement parts needed for repair
e. Cannot be repaired

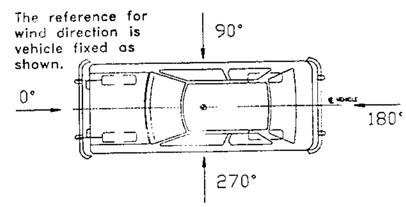
CRASH TEST 404211-8 (*NCHRP REPORT 350* TEST NO. 3-11)

Test Vehicle

A 1995 Chevrolet 2500 pickup truck, shown in figures 5 and 6, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2000 kg. The height to the lower edge of the vehicle front bumper was 400 mm and to the upper edge of the front bumper was 620 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 12. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Soil and Weather Conditions

The crash test was performed the morning of February 16, 2000. No rainfall was recorded for the ten days prior to the test. Soil moisture content was 7.4 percent, 10.6 percent, and 7.9 percent at posts 11, 12, and 13, respectively. Weather conditions at the time of testing were as follows: Wind Speed: 10 km/h; Wind Direction: 180 degrees with respect to the vehicle (vehicle was traveling northerly direction); Temperature: 25°C; Relative Humidity: 60 percent.



Impact Description

The 2000P vehicle, traveling at a speed of 101.4 km/h, impacted the Washington 3-strand cable barrier at post 11 at an angle of 24.8 degrees. At 0.039 s, the left front corner of the vehicle lightly contacted post 11, and at 0.041 s, post 11 moved. The lower cable detached from post 11 at 0.068 s and at 0.071 s, post 12 moved. At 0.073 s, the upper cable detached from post 11, and at 0.096 s, the vehicle began to redirect at 0.096 s. By 0.114 s, the lower cable detached from post 12, and by 0.122 s, the upper cable detached from post 12. The lower and upper cables detached from post 10 at 0.124 s and 0.146 s, respectively. At 0.164 s, the lower cable detached from post 3, and at 0.166 s, the middle cable rode over the top of post 12. The left front bumper contacted at post 12 at 0.188 s, and at 0.190 s, post 13 moved. The right front tire contacted post 12 and the upper cable detached from post 13 at 0.193 s. By 0.217 s, the lower cable detached from post 14, and by 0.222 s, post 12 rotated in the ground. At 0.239 s, the middle cable detached from all posts downstream, and at 0.243 s, the upper cable detached from post 14. The left front tire rode over the lower cable on the ground, and the lower cable detached from post 15 at 0.251 s. The middle cable rode over the top of post 13 and the upper cable detached from post 15 at 0.283 s. By 0.299 s, the lower cable detached from post 16, and by 0.314 s, the middle cable detached at post 14 and post 14 moved. The upper cable detached from post 16 at 0.365 s, and at 0.370 s, the lower cable broke away from post 17. The middle cable rode over the top of posts 11 and 14 at 0.382 s and 0.391 s, respectively. The middle cable detached at post 15

Figure 5. Vehicle/installation geometrics for test 404211-8.

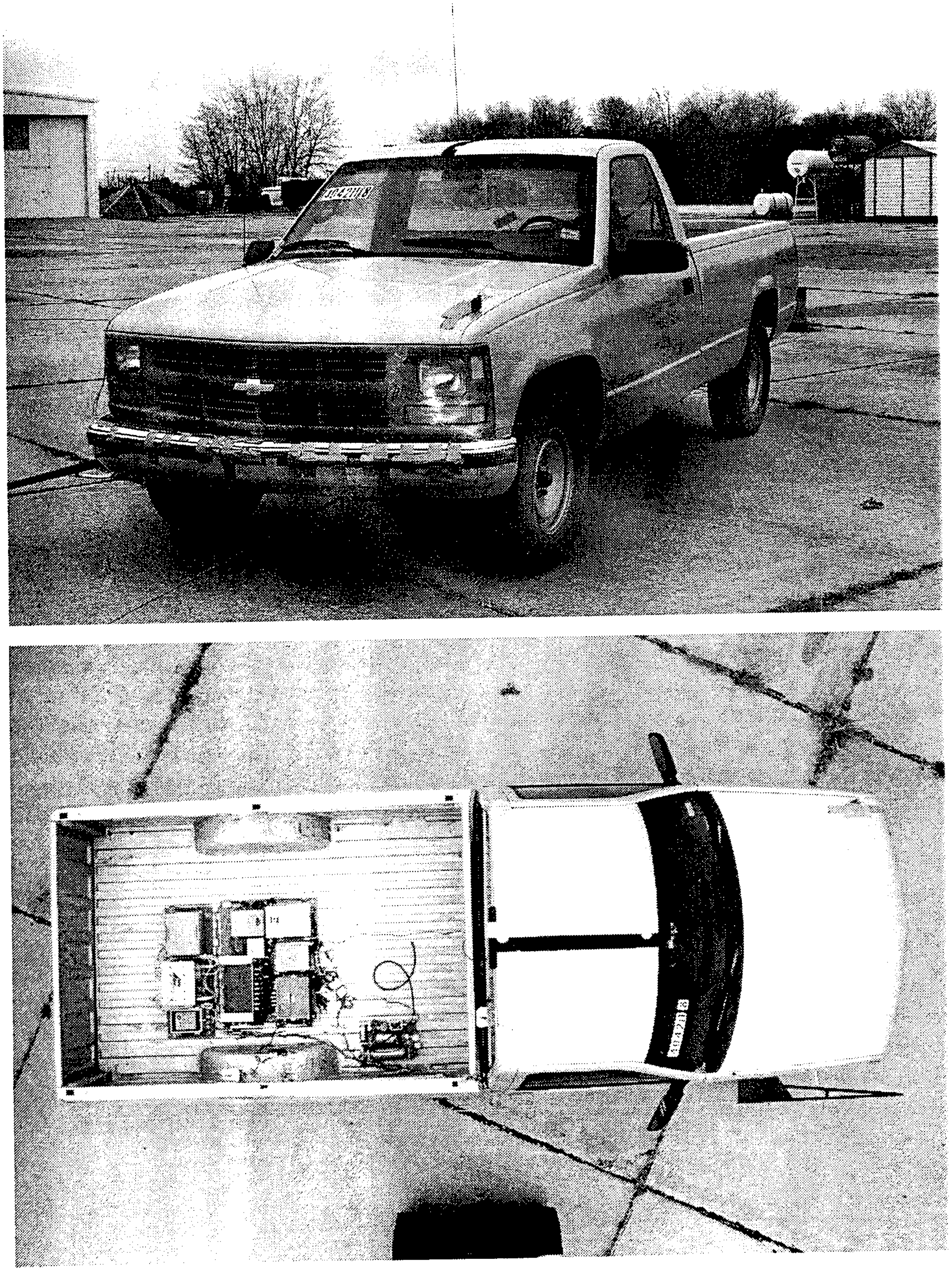


Figure 6. Vehicle before test 404211-8.

at 0.412 s, and at 0.417 s, post 15 moved. By 0.425 s, the upper cable detached from post 17, and by 0.449 s, post 16 moved. The vehicle began to travel parallel with the test installation at 0.464 s and was traveling at a speed of 83.6 km/h. The middle cable rode over the top of post 15 at 0.465 s. At 0.536 s, the middle cable detached from post 16, and at 0.561 s, the front wheels began to steer toward the cable barrier. The middle cable rode over the top of post 16 and post 17 began to deform toward the field side of the installation at 0.653 s. By 0.665 s, the vehicle began to yaw toward the cable barrier, and by 0.819 s, the middle cable rode over the top of post 17. At 0.970 s, the vehicle began to be pulled sideways toward the posts, and at 1.613 s, the vehicle was again parallel with the installation. The side of the vehicle contacted post 18 at 1.705 s, and at 1.895 s, the front bumper makes contact with the post. The vehicle, traveling parallel with the installation, then yawed toward the rail. At this point, 65 percent of the vehicle was estimated to be on the back side of the posts at 2.550 s. The vehicle stopped moving forward at 3.915 s, and at 4.035 s, the front wheels of the vehicle straighten as the vehicle began moving backwards. The vehicle stopped moving at 5.547 s. Brakes on the vehicle were not applied and the vehicle subsequently came to rest on top of post 22. Sequential photographs of the test period are shown in appendix C, figures 14 and 15.

Damage to Test Article

Other than damage to the posts, damage to the Washington 3-strand cable barrier was minimal as shown in figures 7 through 9. The upstream anchor had minor stress cracks radiating from the anchor bolts in the concrete footing. Post 1 moved 670 mm longitudinally downstream. Posts 2 through 9 were disturbed and posts 10 through 15 were displaced 25 mm, 13 mm, 40 mm, 45 mm, 15 mm and 40 mm, respectively. Posts 11 through 17 were rotated and post 12 was torn on the flange above the soil plate. The downstream anchor moved 5 mm longitudinally upstream. The cables were slack throughout the length of the installation. Maximum dynamic deflection during the test was 3.4 m.

Vehicle Damage

The vehicle sustained minor damage as shown in figure 10. There were scuff marks on the left front and rear quarter panels and left door. In addition, the left front and rear tires were cosmetically damaged. Maximum exterior crush to the vehicle was 320 mm above the front bumper at the left front corner. No deformation or intrusion into the occupant compartment occurred from the impact with the cable barrier. The interior of the vehicle is shown in figure 11. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 3 and 4.

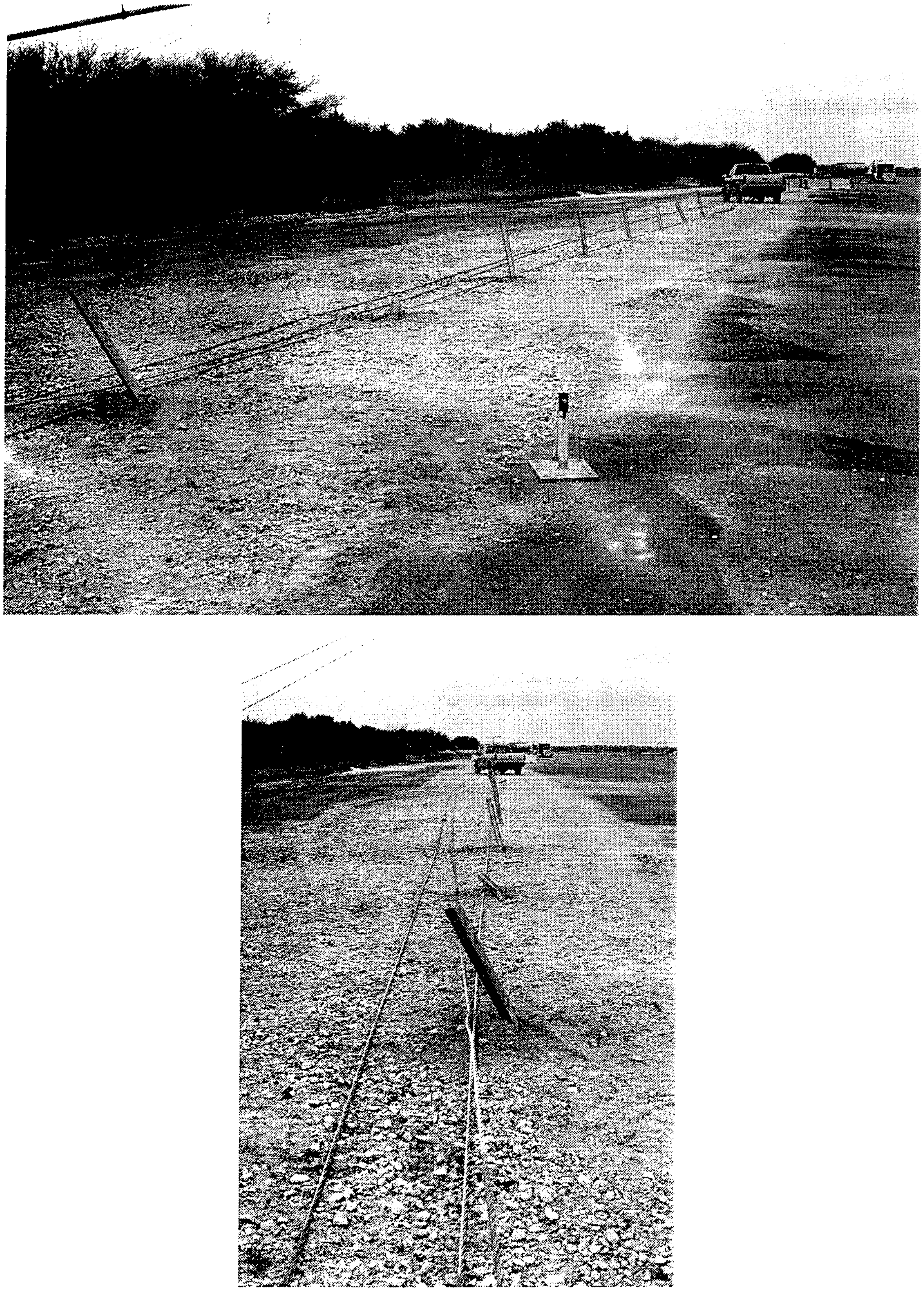


Figure 7. Vehicle trajectory path after test 404211-8.

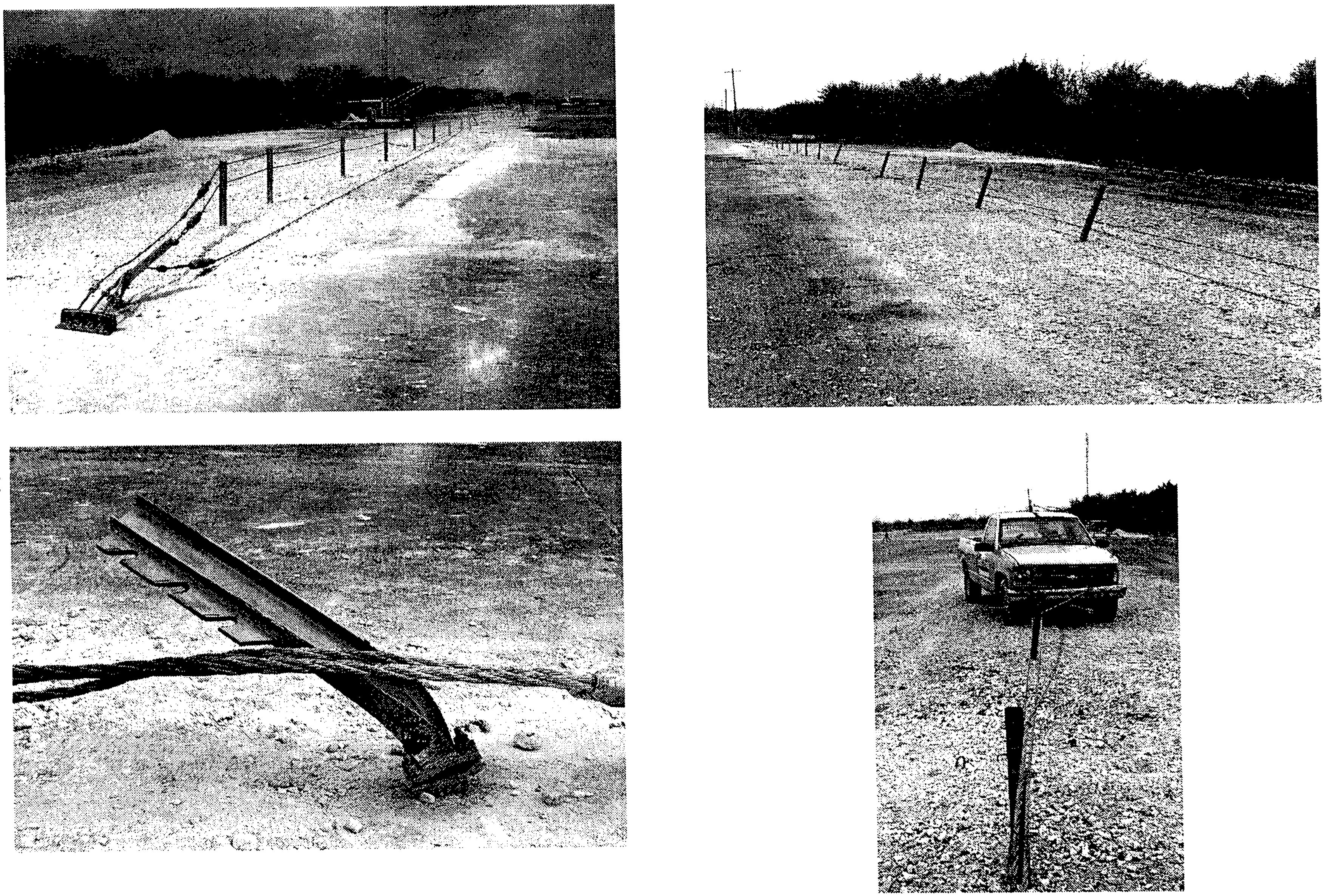
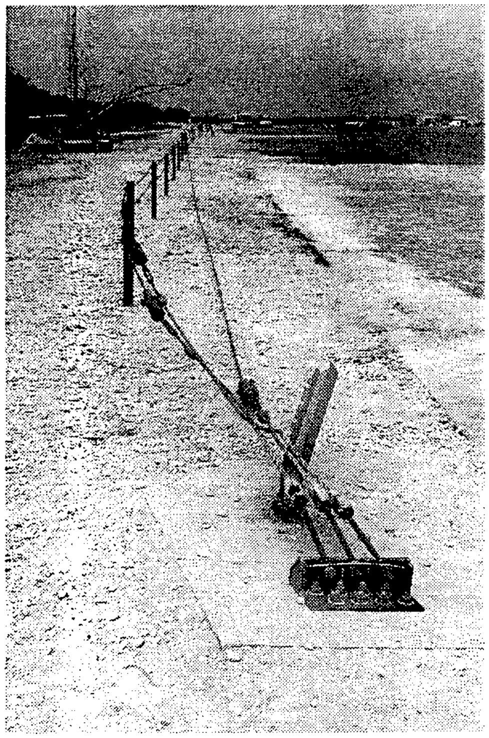


Figure 8. Installation after test 404211-8.



Upstream anchor

Downstream anchor

Figure 9. End terminals after test 404211-8.

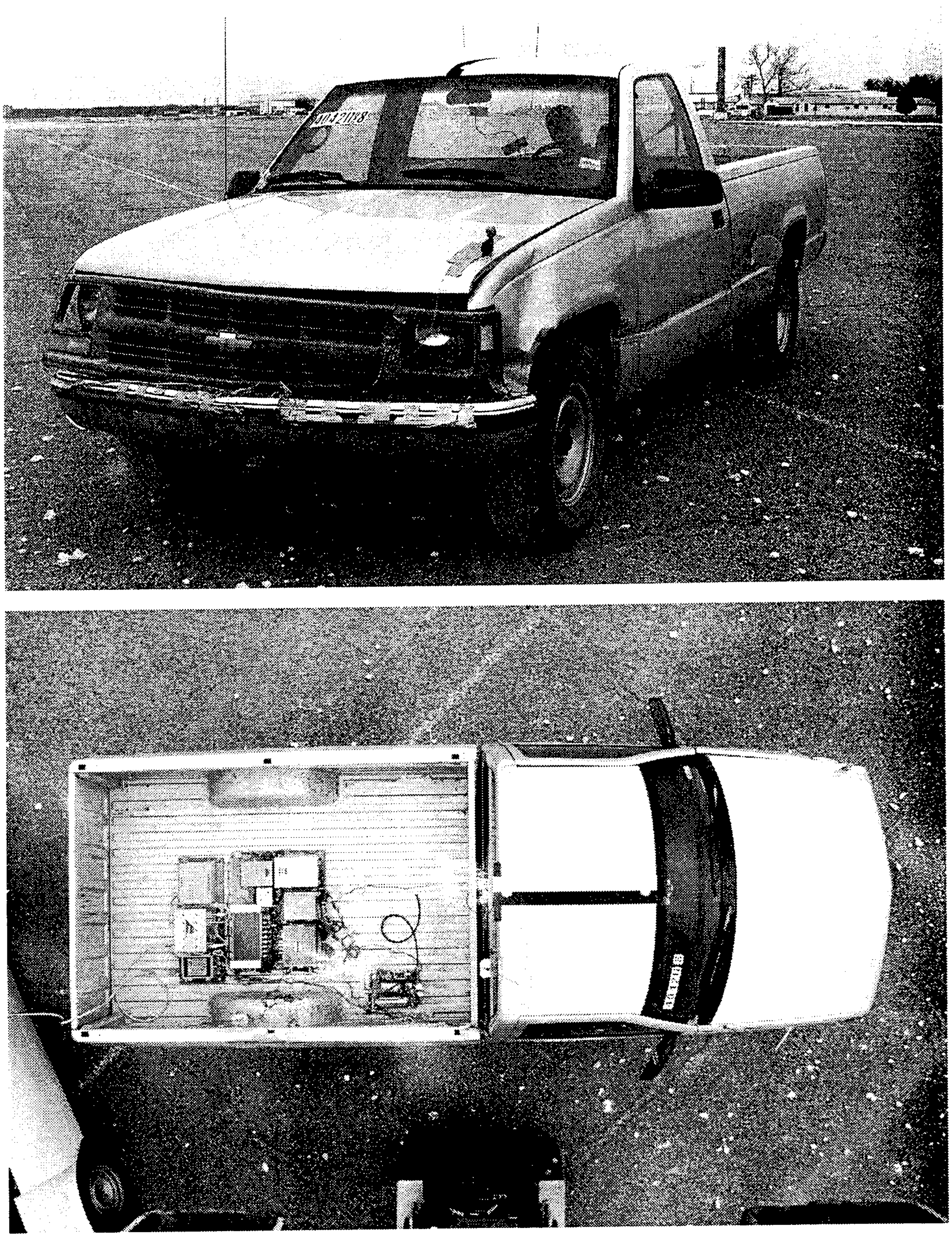
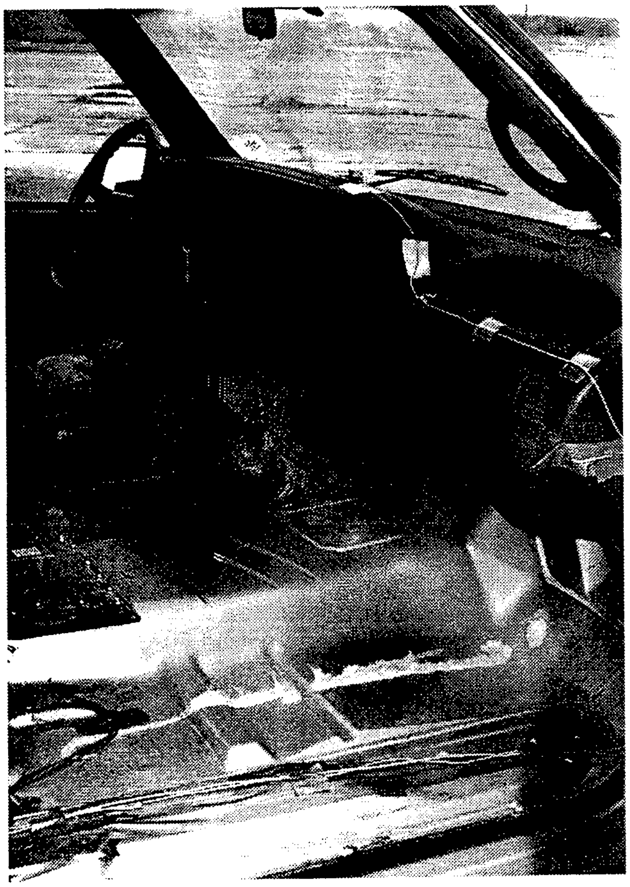


Figure 10. Vehicle after test 404211-8.



Before test

After test

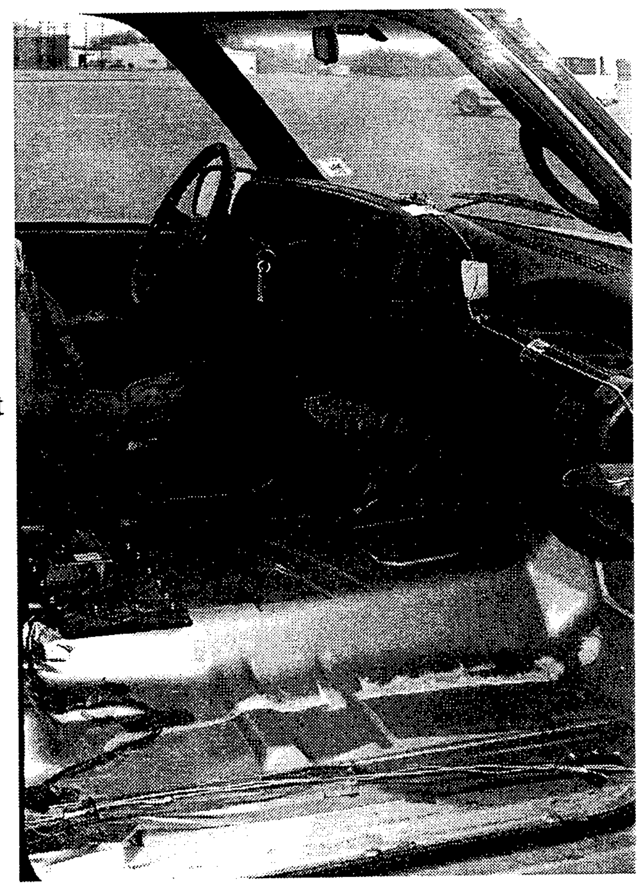
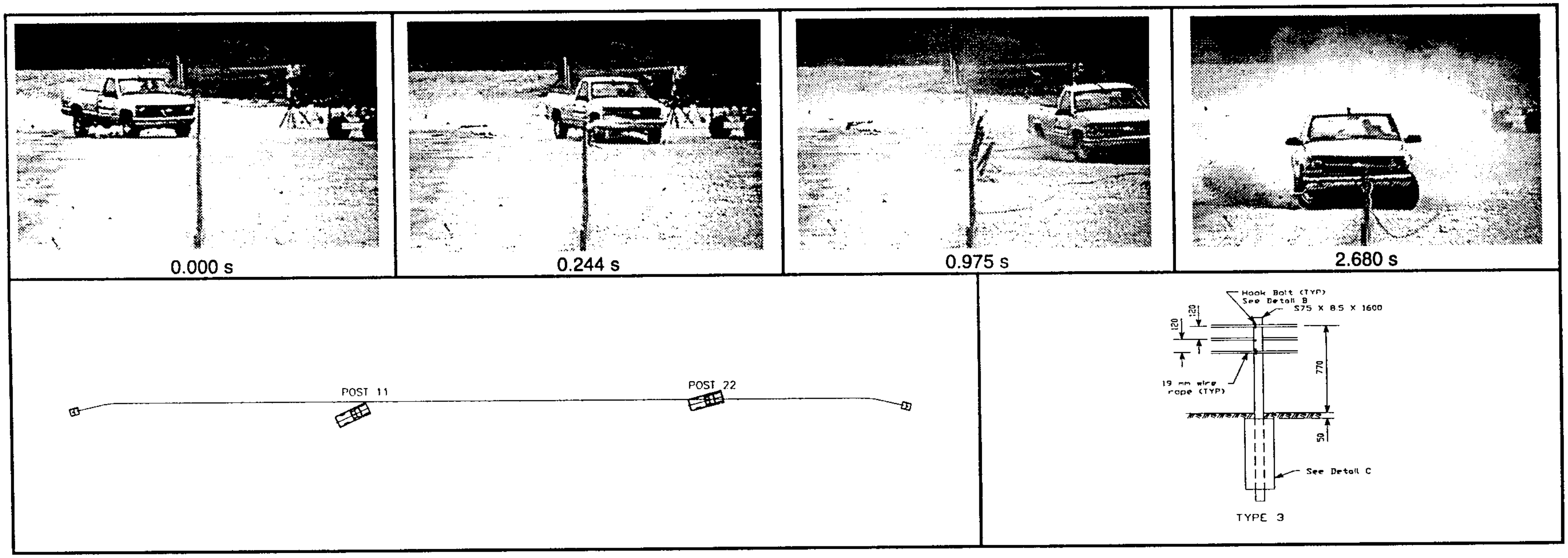


Figure 11. Interior of vehicle for test 404211-8.

Occupant Risk Factors

Data from the triaxial accelerometer, located at the vehicle center of gravity, were digitized to compute occupant impact velocity and ridedown accelerations. The occupant impact velocity and ridedown accelerations in the longitudinal axis only are required from these data for evaluation of criterion L of *NCHRP Report 350*. In the longitudinal direction, occupant impact velocity was 2.2 m/s at 0.240 s, maximum 0.010-s ridedown acceleration was -2.7 g's from 0.546 to 0.556 s, and the maximum 0.050-s average was -1.6 g's between 0.137 and 0.187 s. In the lateral direction, the occupant impact velocity was 2.9 m/s at 0.240 s, the highest 0.010-s occupant ridedown acceleration was 4.9 g's from 0.360 to 0.370 s, and the maximum 0.050-s average was 2.1 g's between 0.348 and 0.398 s. These data and other information pertinent to the test are presented in figure 12. Vehicle angular displacements and accelerations versus time traces are shown in appendix E, figures 16 through 27.



General Information	
Test Agency	Texas Transportation Institute
Test No.	404211-8
Date	02/16/00
Test Article	
Type	Cable Barrier
Name	WSDOT Cable Rail with NY terminal
Installation Length (m)	145.0
Material or Key Elements	3 Strand Wire Cable, Top at 770 mm, with New York Cable Terminal
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1994 Chevrolet 2500 Pickup Truck
Mass (kg)	
Curb	1932
Test Inertial	2000
Dummy	No dummy
Gross Static	2000

Impact Conditions	
Speed (km/h)	101.4
Angle (deg)	24.8
Exit Conditions	
Speed (km/h)	Stopped
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.2
y-direction	2.9
THIV (km/h)	12.0
Ridedown Accelerations (g's)	
x-direction	-2.7
y-direction	4.9
PHD (g's)	5.2
ASI	0.26
Max. 0.050-s Average (g's)	
x-direction	-1.6
y-direction	2.1
z-direction	-1.2

Test Article Deflections (m)	
Dynamic	3.4
Permanent	0.7
Vehicle Damage	
Exterior	
VDS	11LFQ2
CDC	11FLEK2 & 11LDEW2
Maximum Exterior Vehicle Crush (mm)	320
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	18
Max. Pitch Angle (deg)	3
Max. Roll Angle (deg)	-3

Figure 12. Summary of results for test 404211-8, *NCHRP Report 350* test 3-11.

SUMMARY AND CONCLUSIONS

ASSESSMENT OF TEST RESULTS

As stated previously, the following *NCHRP Report 350* safety evaluation criteria were used to evaluate this crash test:

- **Structural Adequacy**

  A. *Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*

  The Washington 3-strand cable barrier contained and redirected the 2000P vehicle. Maximum dynamic deflection of the barrier was 3.4 m.

- **Occupant Risk**

  D. *Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.*

  No detached elements, fragments or debris were present to penetrate or to show potential for penetrating the occupant compartment, nor to present undue hazard to others in the area. No deformation or intrusion of the occupant compartment occurred.

  F. *The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.*

  The vehicle remained upright during and after the collision period.

Preceding Page Blank

- **Vehicle Trajectory**

K. *After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*

The vehicle did not intrude into adjacent traffic lanes. Final rest of the vehicle was over post no. 22.

L. *The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.*

The longitudinal occupant impact velocity was 2.2 m/s and ridedown acceleration was -2.7 g's.

M. *The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.*

The vehicle did not exit the test installation.

The following supplemental evaluation factors and terminology were used for visual assessment of test results:

◆ **PASSENGER COMPARTMENT INTRUSION**

1. **Windshield Intrusion**

   a. No windshield contact
   b. Windshield contact, no damage
   c. Windshield contact, no intrusion
   d. Device embedded in windshield, no significant intrusion
   e. Complete intrusion into passenger compartment
   f. Partial intrusion into passenger compartment

2. **Body Panel Intrusion** yes or no

◆ **LOSS OF VEHICLE CONTROL**

1. **Physical loss of control**
2. **Loss of windshield visibility**
3. **Perceived threat to other vehicles**
4. **Debris on pavement**

The vehicle could have been kept under control, there was no loss of visibility, no perceived threat to other vehicles, and no debris on pavement.

- **PHYSICAL THREAT TO WORKERS OR OTHER VEHICLES**

  1. **Harmful debris that could injure workers or others in the area**
  2. **Harmful debris that could injure occupants in other vehicles**

No debris of significance that would harm others in the area was present.

- **VEHICLE AND DEVICE CONDITION**

  1. **Vehicle Damage**

     a. None
     b. Minor scrapes, scratches or dents
     c. Significant cosmetic dents
     d. Major dents to grill and body panels
     e. Major structural damage

  2. **Windshield Damage**

     a. None
     b. Minor chip or crack
     c. Broken, no interference with visibility
     d. Broken and shattered, visibility restricted but remained intact
     e. Shattered, remained intact but partially dislodged
     f. Large portion removed
     g. Completely removed

  3. **Device Damage**

     a. None
     b. Superficial
     c. Substantial, but can be straightened
     d. Substantial, replacement parts needed for repair
     e. Cannot be repaired

CONCLUSIONS

As shown in table 1, the Washington 3-strand cable barrier met all criteria specified for *NCHRP Report 350* test designation 3-11. The installation permitted 3.4 m of lateral deflection, redirected the vehicle and brought it to a safe controlled stop within the installation. The Washington 3-strand cable barrier performs well where space permits the lateral deflections.

Table 1. Performance evaluation summary for test 404211-8, *NCHRP Report 350* test 3-11.

Test Agency: Texas Transportation Institute | Test No.: 404211-8 | Test Date: 02/16/2000

NCHRP Report 350 **Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The Washington 3-strand cable barrier contained and redirected the 2000P vehicle. Maximum lateral deflection of the barrier was 3.4 m.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	No detached elements, fragments or debris were present to penetrate or to show potential for penetrating the occupant compartment, nor to present undue hazard to others in the area. No deformation or intrusion of the occupant compartment occurred.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during and after the collision period.	Pass
Vehicle Trajectory		
K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes as the vehicle came to rest over post 22.	Pass*
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	The longitudinal occupant impact velocity was 2.2 m/s and ridedown acceleration was -2.7 g's.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The vehicle did not exit the test installation.	N/A*

*Criterion K and M are preferable, not required.

APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented as follows.

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The test vehicle was instrumented with five uniaxial accelerometers mounted in the following locations: (1) center top surface of the instrument panel; (2) inside end of right front wheel spindle; (3) inside end of left front wheel spindle; (4) top of engine block; and (5) bottom of engine block. The exact location of each accelerometer was measured and is reported in table 2. These accelerometers are ENDEVCO Model 7264B low mass piezoresistive accelerometers with a ±2000 g range.

Table 2. Locations of vehicle accelerometers for test 404211-8.

Location	X (mm)* (distance from front axle)	Y (mm)* (distance from centerline)	Z (mm)* (distance from ground)	Data Axis
Instrument panel	-850	0	-1360	+X
Right front wheel spindle	0	+720	-370	+X
Left front wheel spindle	0	-720	-370	+Y
Top of engine block	+80	+60	-880	+X
Bottom of engine block	-370	0	-360	+X
Vehicle c.g.	-1480	0	-720	+X,+Y,+Z
Vehicle rear axle	-3395	0	-870	+X,+Y,+Z

*Reference point:	X=0 at front axle	Y=0 at centerline	Z=0 at ground
Sign convention:	+X=forward	+Y=right	+Z=down

On-board data acquisition is provided by a 16 channel, Prosig P4010 system. Each analog channel has integral signal conditioning, fixed frequency anti-alias filtering, and a programmable transducer bridge power supply. Each P4010, 4 channel POD contains one megabyte of battery backed memory allowing for more than 13 seconds of storage at a maximum of 10,000 samples per second per channel. All channels are synchronized by a common external clock. The accuracy of this system is ±0.1%.

In addition, the test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch, and yaw rates; a triaxial accelerometer near the vehicle center of gravity (c.g.) to measure longitudinal, lateral, and vertical acceleration levels; and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. These accelerometers are ENDEVCO Model 2262CA, piezoresistive accelerometers with a ±100 g range.

The accelerometers are strain gage type with a linear millivolt output proportional to acceleration. Rate of turn transducers are solid state, gas flow units designed for high g service. Signal conditioners and amplifiers in the test vehicle increase the low level signals to a ±2.5 volt maximum level. The signal conditioners also provide the capability of an R-Cal or shunt calibration for the accelerometers and a precision voltage calibration for the rate transducers. The electronic signals from the accelerometers and rate transducers are transmitted to a base station by means of a 15 channel, constant bandwidth, Inter-Range Instrumentation Group (I.R.I.G.), FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals, from the test vehicle, are recorded minutes before the test and also immediately afterwards. A crystal controlled time reference signal is simultaneously recorded with the data. Pressure-sensitive switches on the bumper of the impacting vehicle are actuated just prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produces an "event" mark on the data record to establish the exact instant of contact with the installation.

The multiplex of data channels, transmitted on one radio frequency, is received at the data acquisition station, and demultiplexed onto separate tracks of a 28 track, (I.R.I.G.) tape recorder. After the test, the data are played back from the tape machine, filtered with Society of Automotive Engineers (SAE J211) filters, and digitized using a microcomputer, at 2000 samples per second per channel, for analysis and evaluation of impact performance.

All accelerometers are calibrated annually according to SAE J211 *4.6.1* by means of an ENDEVCO 2901, precision primary vibration standard. This device along with its support instruments is returned to the factory annually for a National Institute of Standards Technology (NIST) traceable calibration. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations will be made at any time a data channel is suspected of any anomalies.

The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions of the functions of these two computer programs are provided as follows.

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-ms average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers were then filtered with a 60-Hz digital filter and acceleration versus time curves for the longitudinal, lateral, and vertical directions were plotted using a commercially available software package (Excel).

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0005-s intervals and then instructs a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

ANTHROPOMORPHIC DUMMY INSTRUMENTATION

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the vehicle. The dummy was uninstrumented.

PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed behind the installation at an angle; and a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A flash bulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A 16-mm movie cine, a BetaCam, a VHS-format video camera and recorder, and still cameras were used to record and document conditions of the test vehicle and installation before and after the test.

TEST VEHICLE PROPULSION AND GUIDANCE

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A two to one speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs.

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

DATE: 02-16-00 TEST NO.: 404211-8 VIN NO.: 1GCFC24K1SZ110515

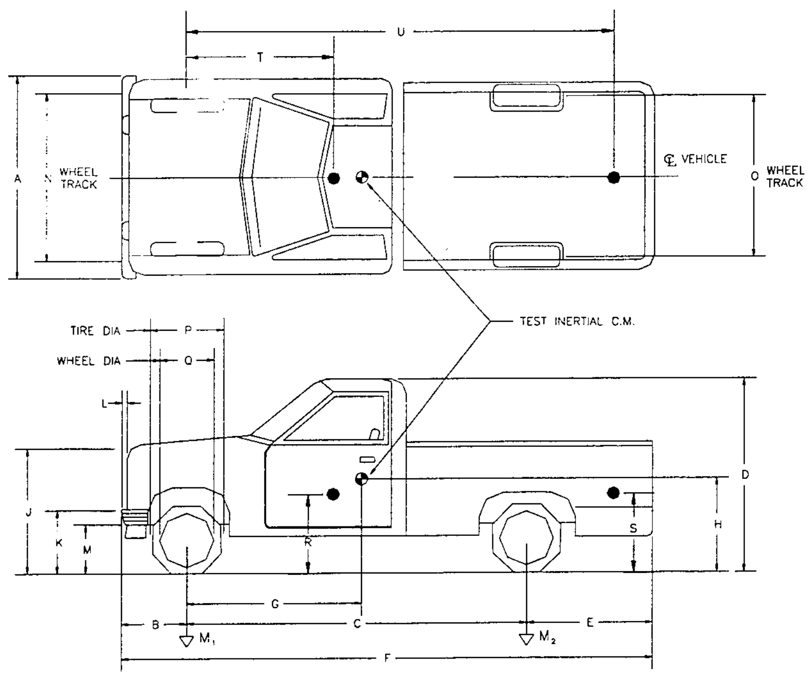
YEAR: 1995 MAKE: Chevrolet MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ______ ODOMETER: 143611 TIRE SIZE: LT 245 75R16

MASS DISTRIBUTION (kg) LF 560 RF 540 LR 455 RR 445

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Dent in Rt Rear Quarter Panel (Marked)



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: [illegible] CYL

ENGINE CID: 5.7L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

6 LUGS

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY - (mm)

A	860	E	1320	J	1050	N	1600	R	700
B	810	F	5480	K	620	O	1620	S	875
C	3350	G	1507.5	L	75	P	750	T	1500
D	1780	H		M	400	Q	445	U	3350

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1110	1100	
M_2	822	900	
M_T	1932	2000	

Figure 13. Vehicle properties for test 404211-8.

Table 3. Exterior crush measurements for test 404211-8.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ ≥ 4 inches ________	Bowing: B1 ____ X1 ____ B2 ____ X2 ____ Bowing constant $\frac{X1 + X2}{2}$ = ____

Note: Measure C1 to C6 from Driver to Passenger side in Front or Rear impacts–
Rear to Front in Side impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width ** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Above front bumper	250	320	340	320	220	100	0			-640
2	650 mm above ground	470	240	1200	0	50	N/A	N/A	210	280	5480

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

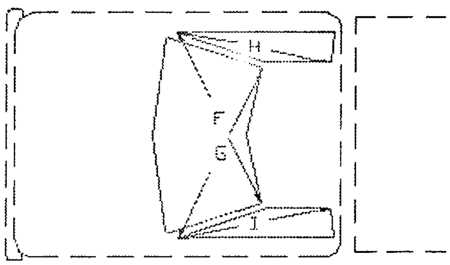
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

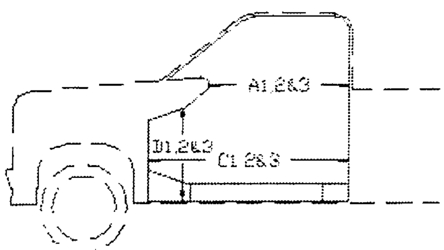
***Measure and document on the vehicle diagram the location of the maximum crush.
Note: Use as many lines/columns as necessary to describe each damage profile.

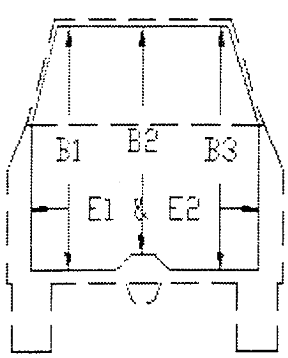
Table 4. Occupant compartment measurements for test 404211-8.

Truck

Occupant Compartment Deformation







	BEFORE	AFTER
A1	867	867
A2	920	920
A3	910	910
B1	1070	1070
B2	1059	1059
B3	1067	1067
C1	1376	1376
C2	1266	1266
C3	1372	1372
D1	311	311
D2	152	152
D3	308	308
E1	1579	1579
E2	1597	1597
F	1475	1475
G	1475	1475
H	800	800
I	800	800

APPENDIX C. SEQUENTIAL PHOTOGRAPHS

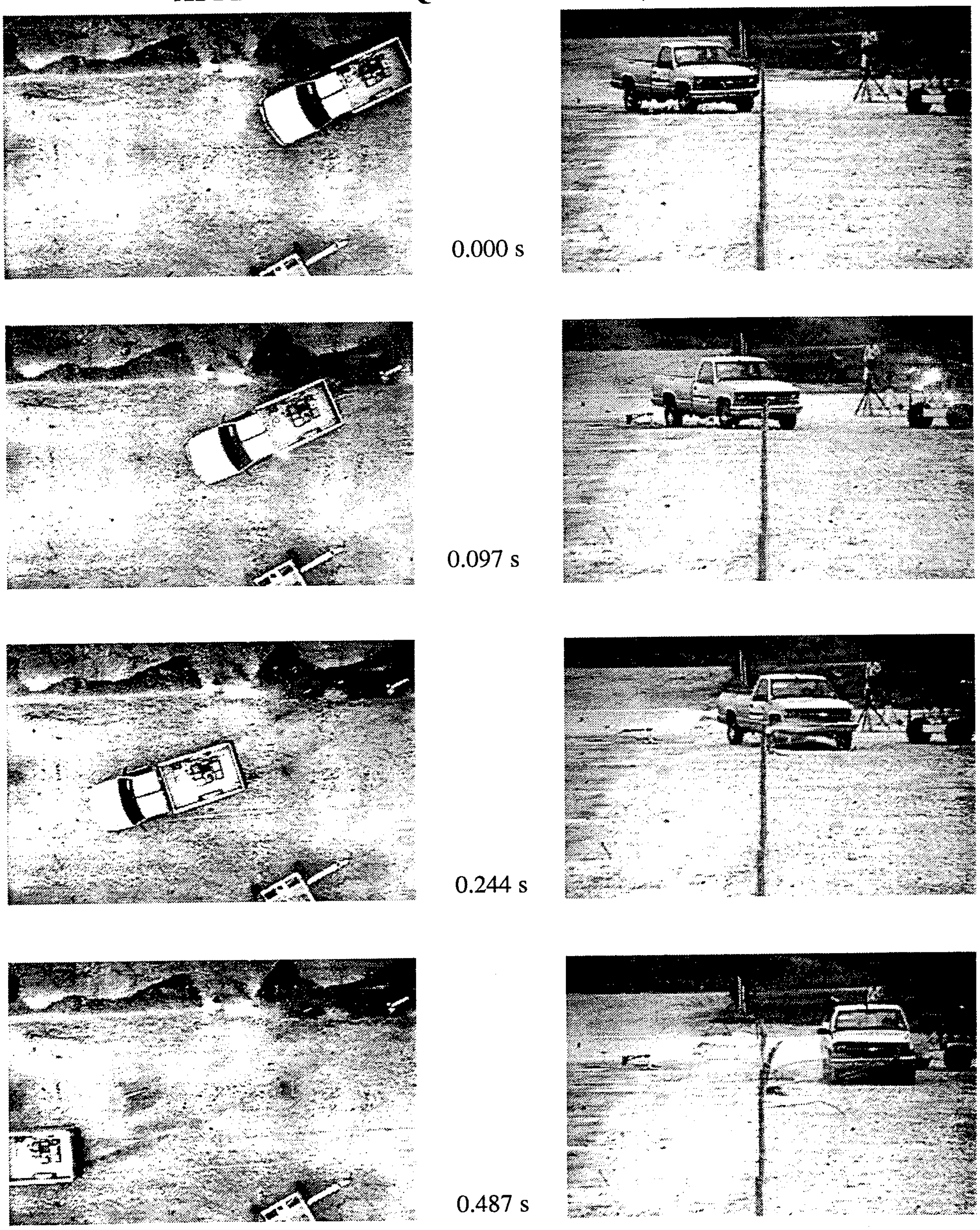
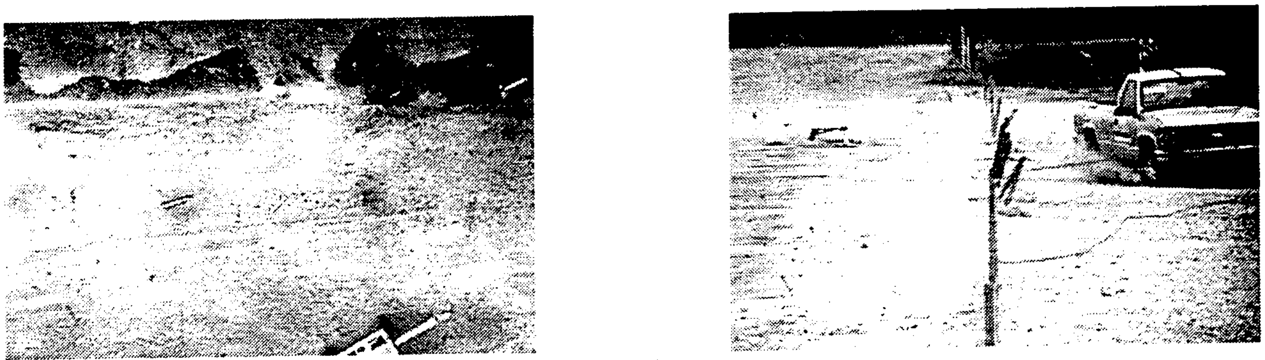
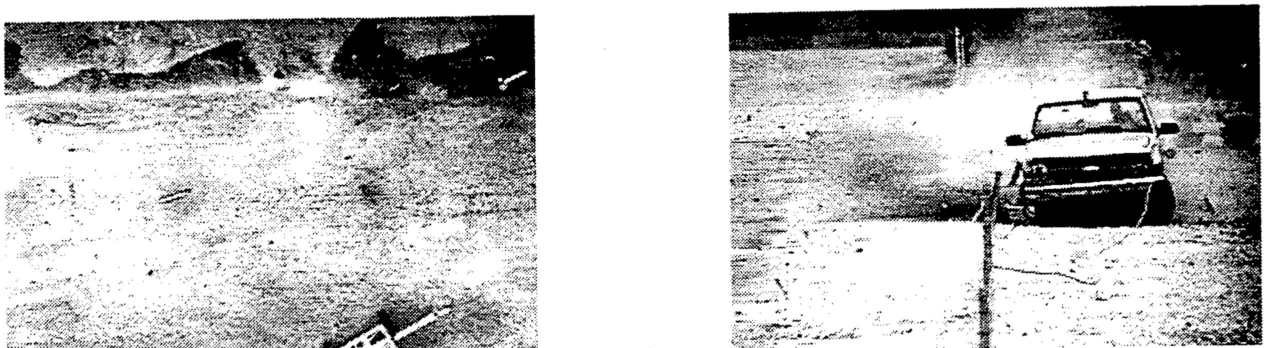


Figure 14. Sequential photographs for test 404211-8
(overhead & frontal views).

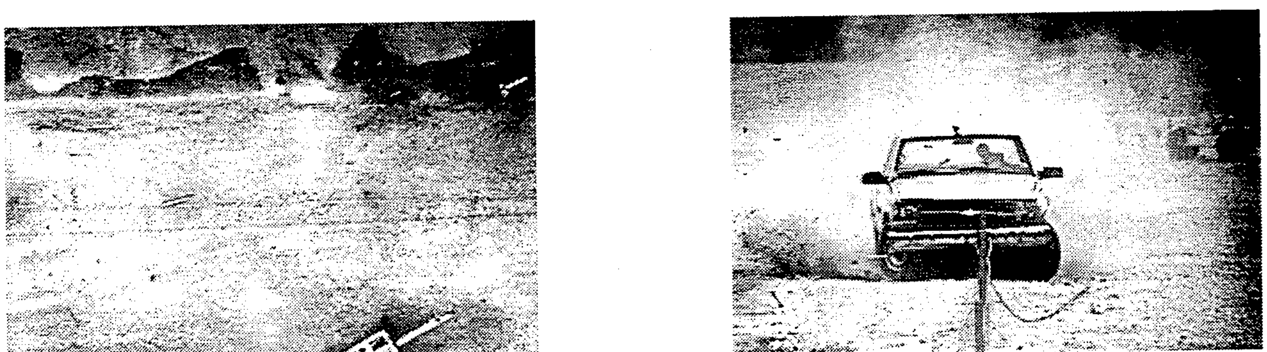
 Preceding Page Blank



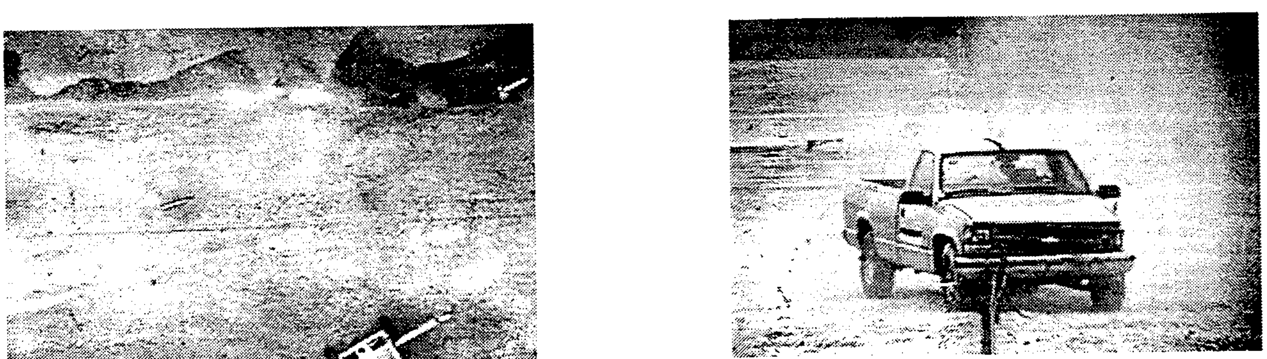
0.975 s



1.705 s

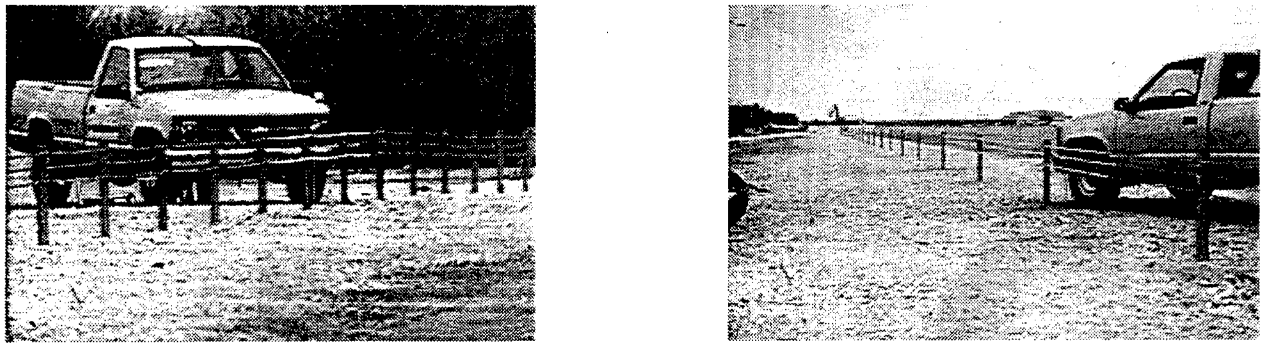


2.680 s

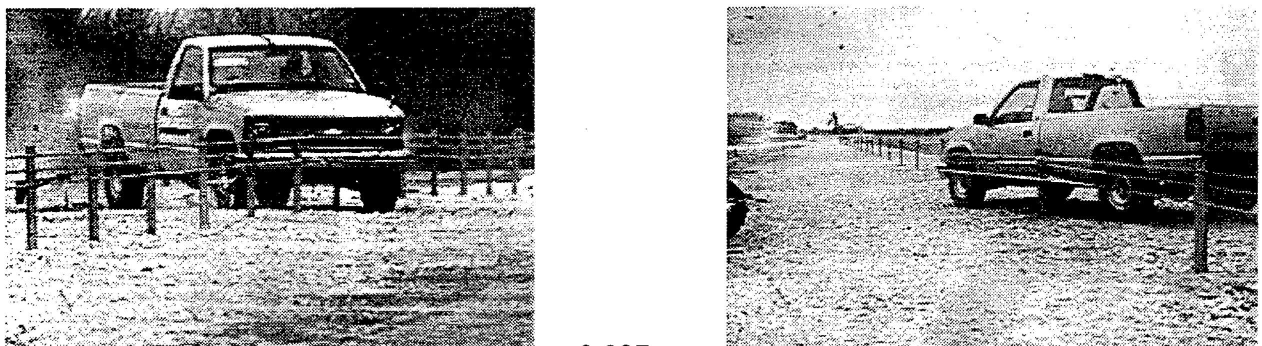


5.603 s

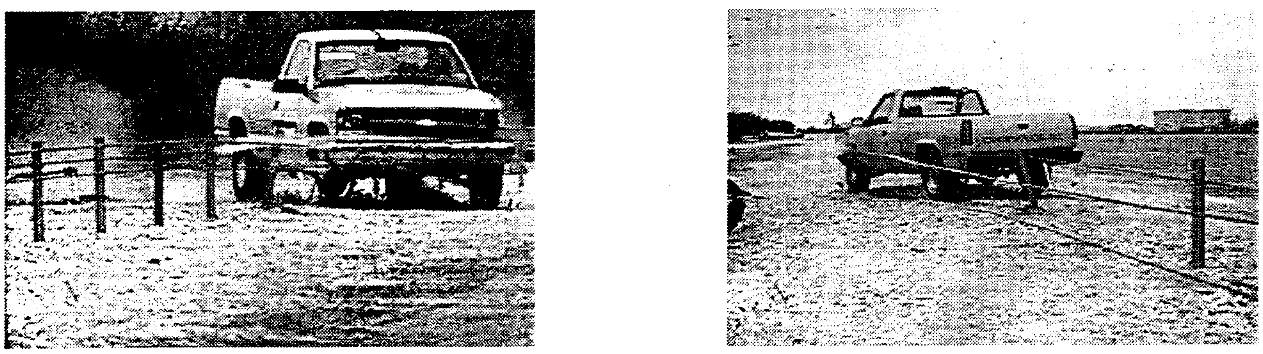
Figure 14. Sequential photographs for test 404211-8
(overhead & frontal views) (continued).



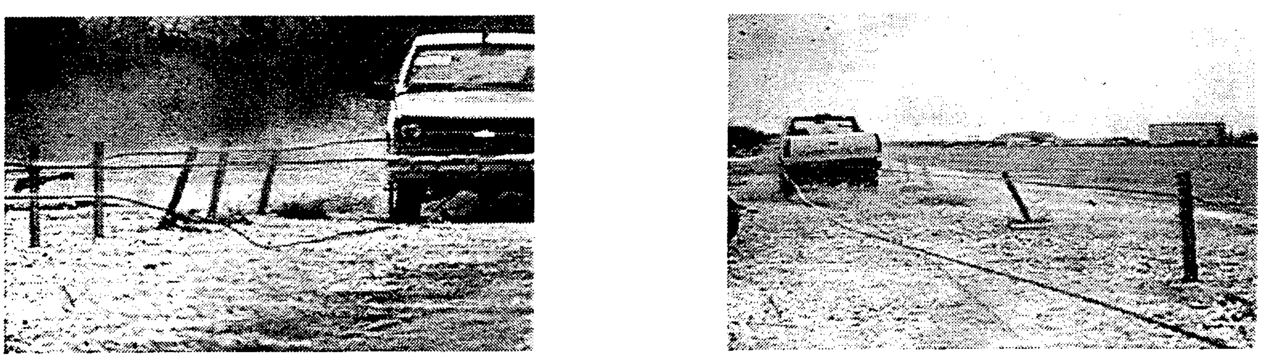
0.000 s



0.097 s

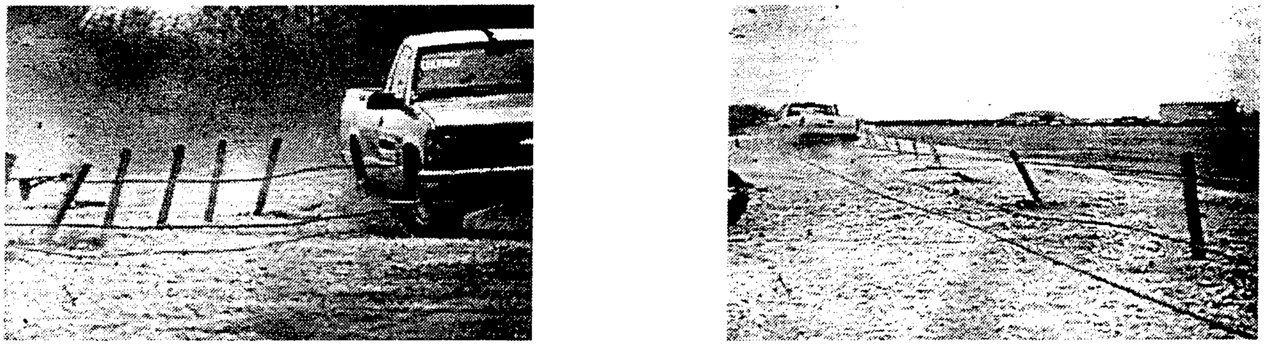


0.244 s

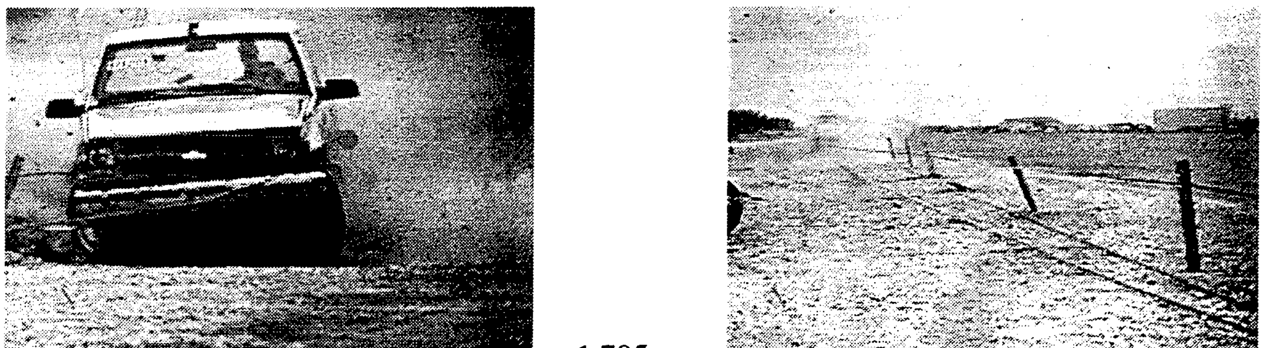


0.487 s

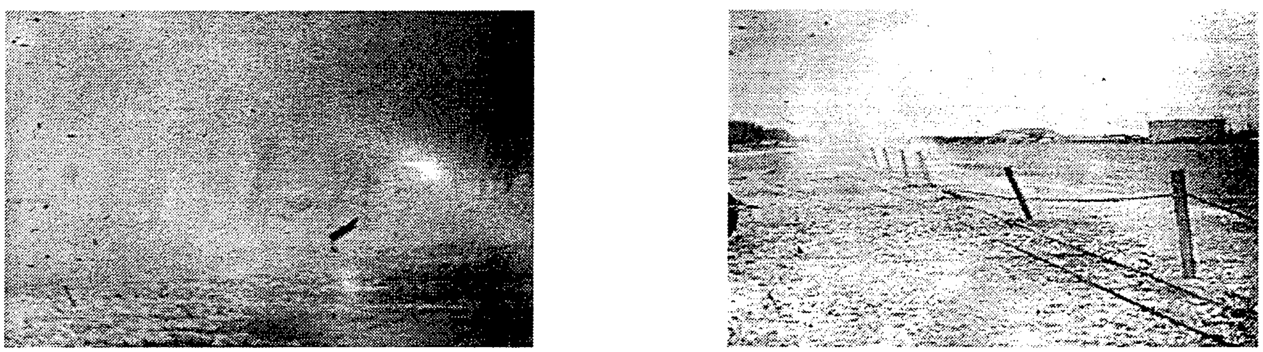
Figure 15. Sequential photographs for test 404211-8
(rear views).



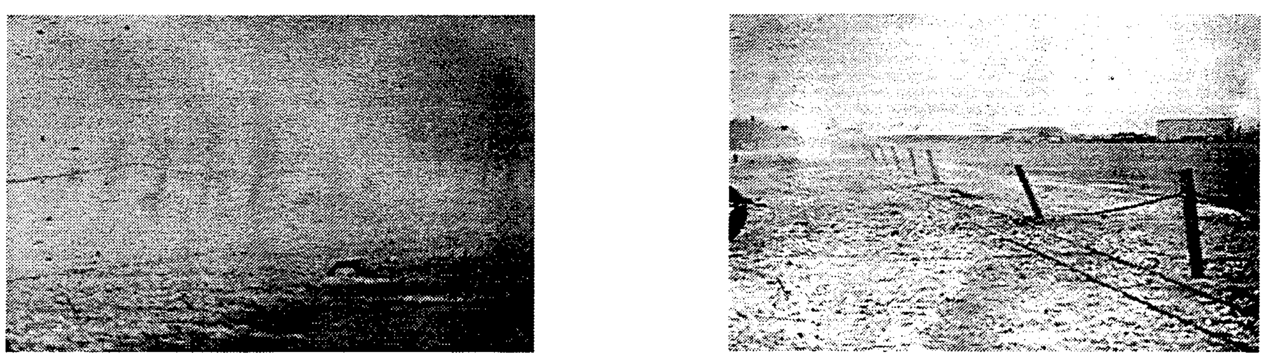
0.975 s



1.705 s



2.680 s



5.603 s

Figure 15. Sequential photographs for test 404211-8
(rear views) (continued).

APPENDIX D. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS

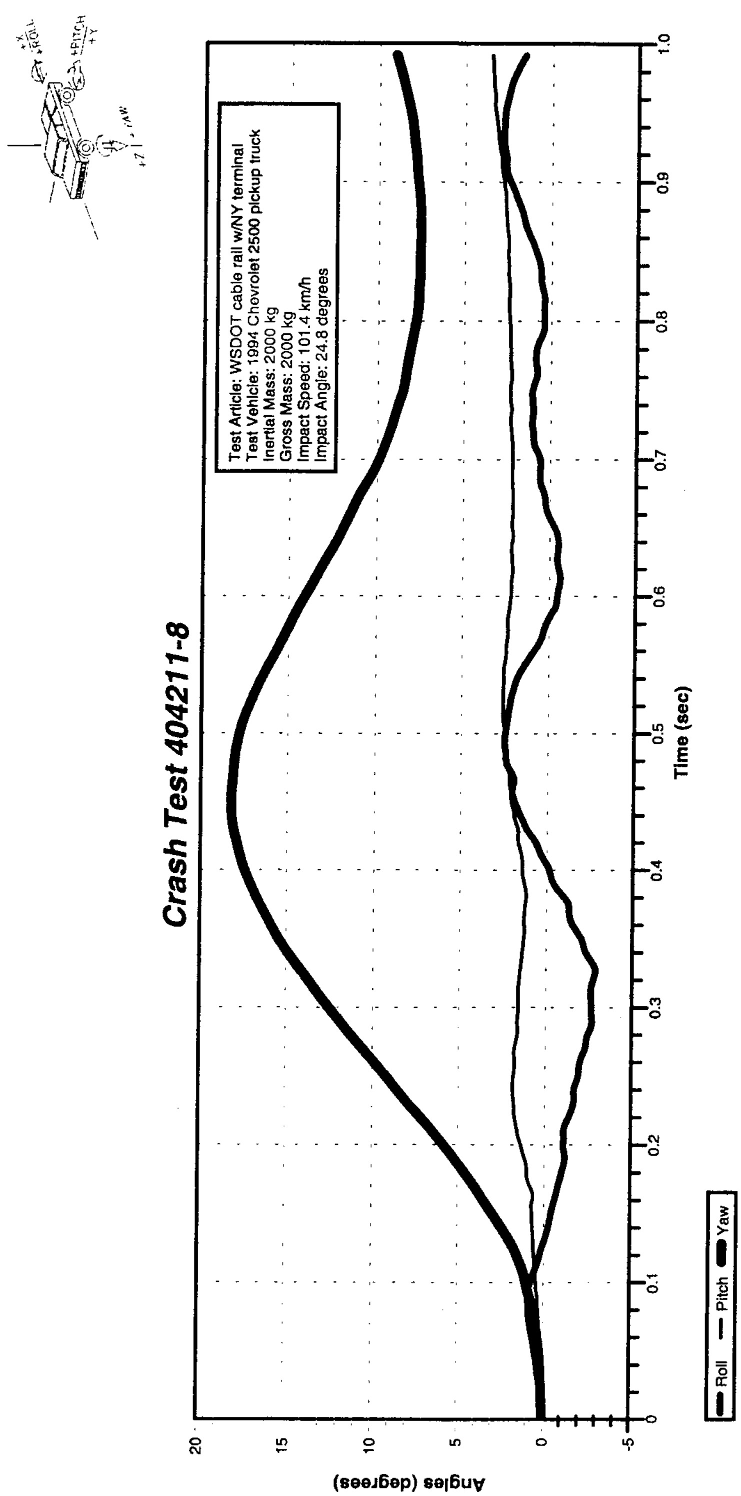


Figure 16. Vehicular angular displacements for test 404211-8.

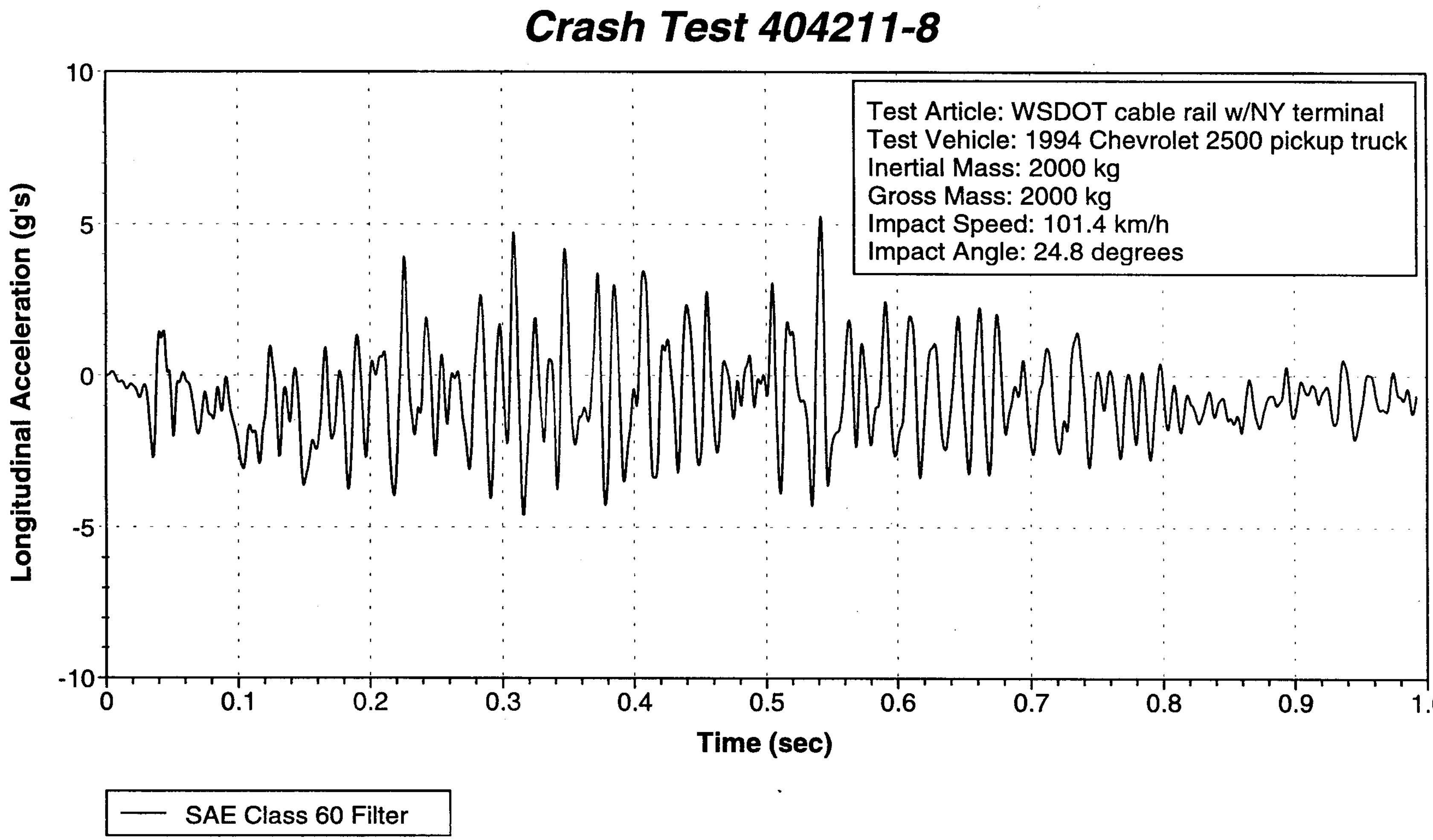


Figure 17. Vehicle longitudinal accelerometer trace for test 404211-8 (accelerometer located at center of gravity).

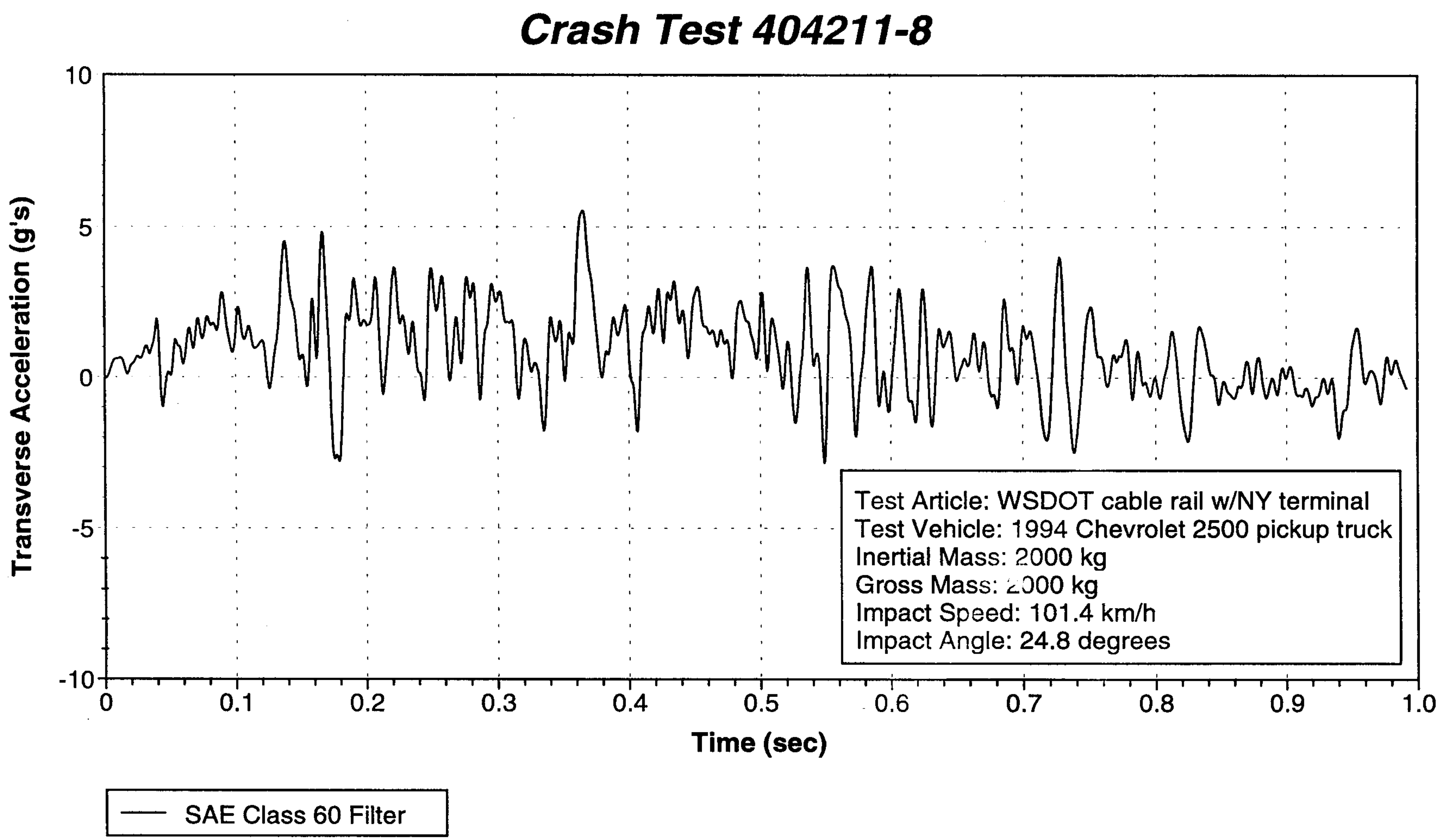


Figure 18. Vehicle lateral accelerometer trace for test 404211-8
(accelerometer located at center of gravity).

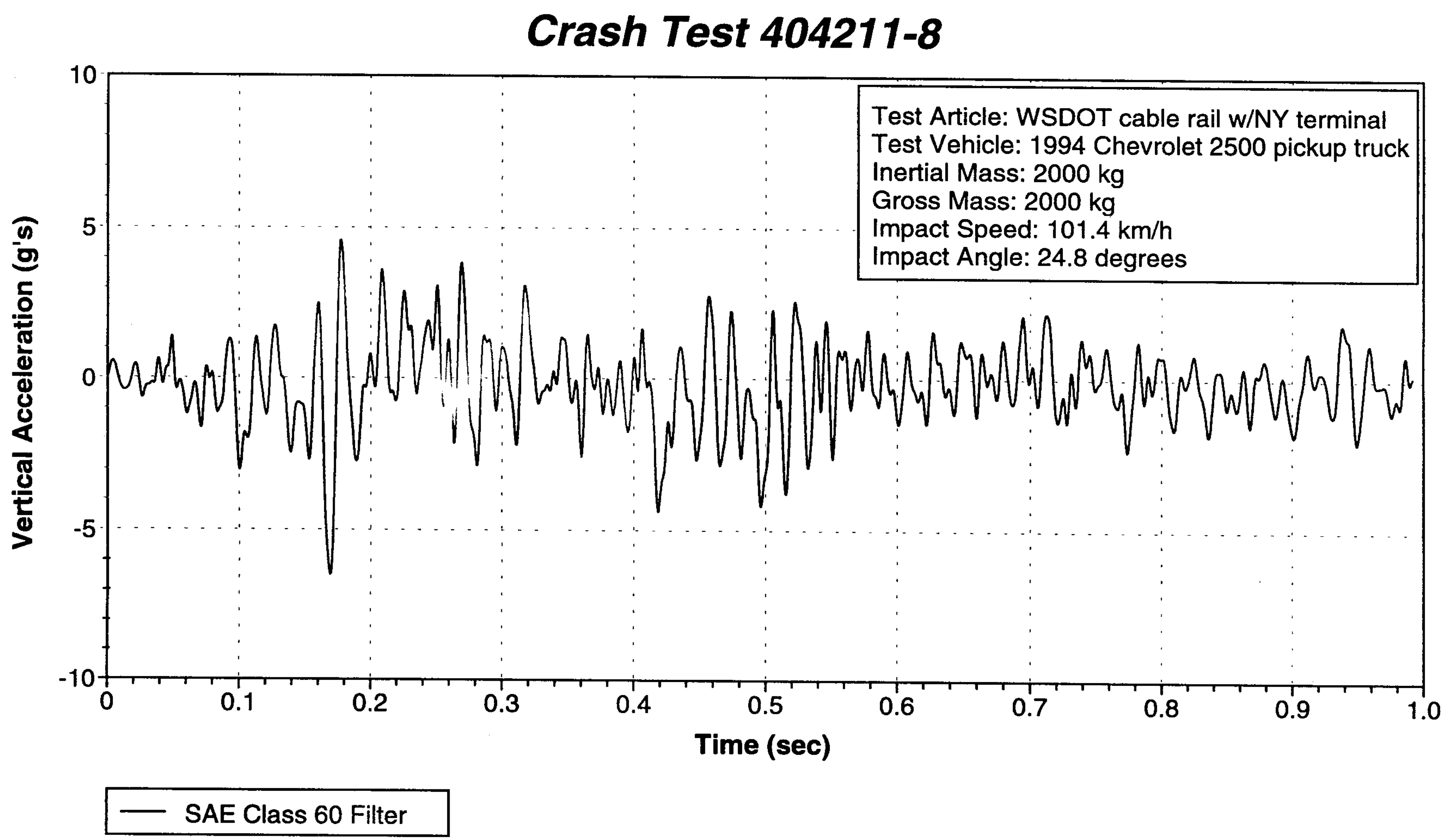


Figure 19. Vehicle vertical accelerometer trace for test 404211-8
(accelerometer located at center of gravity).

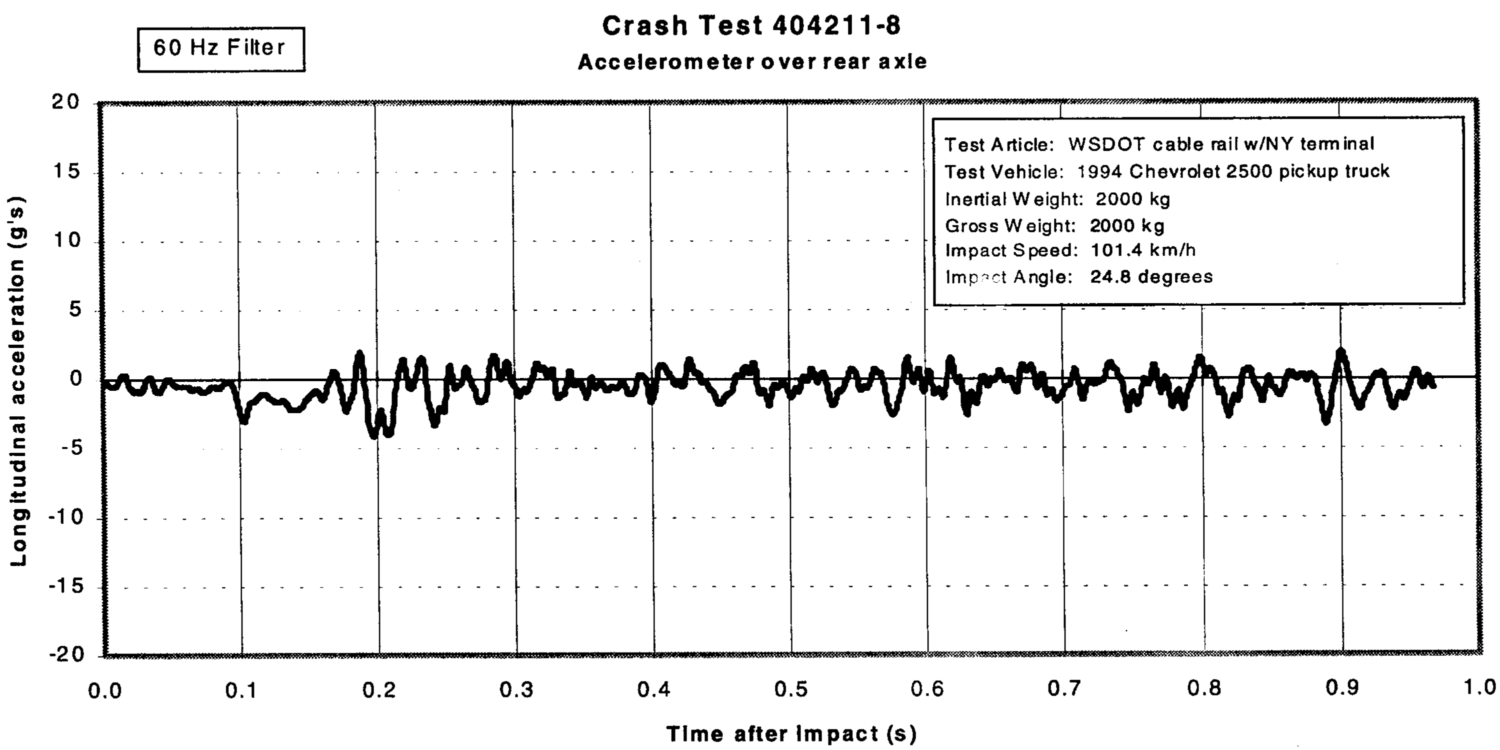


Figure 20. Vehicle longitudinal accelerometer trace for test 404211-8 (accelerometer located over rear axle).

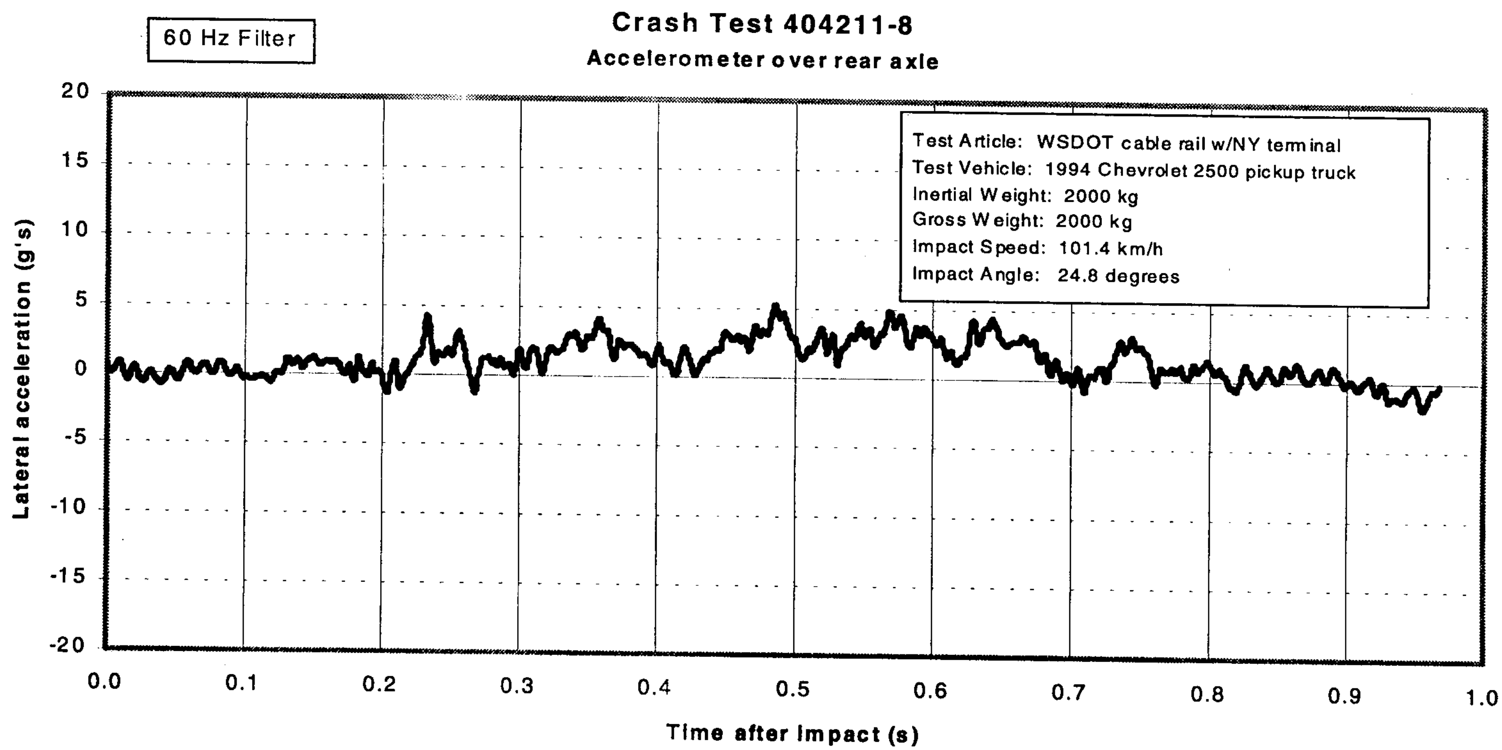


Figure 21. Vehicle lateral accelerometer trace for test 404211-8 (accelerometer located over rear axle).

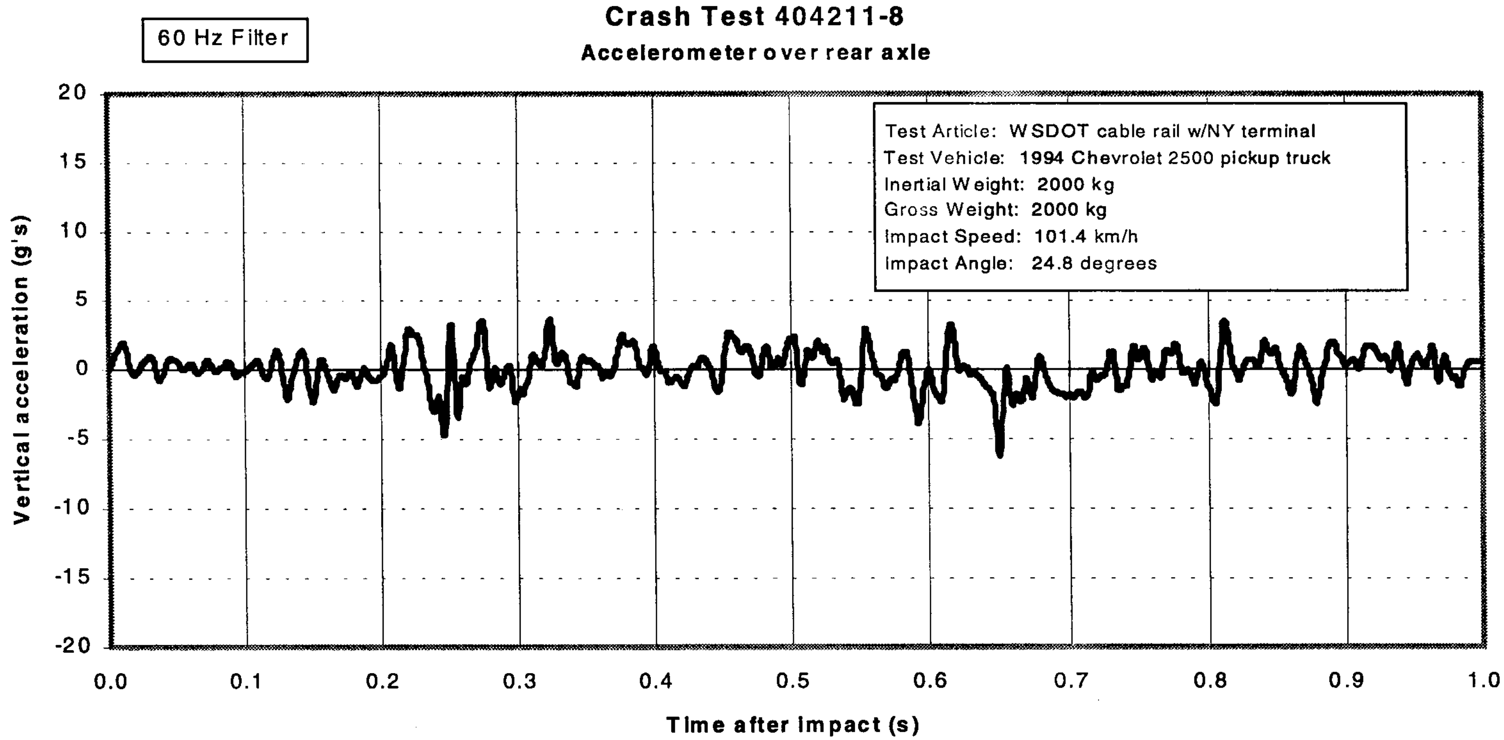


Figure 22. Vehicle vertical accelerometer trace for test 404211-8 (accelerometer located over rear axle).

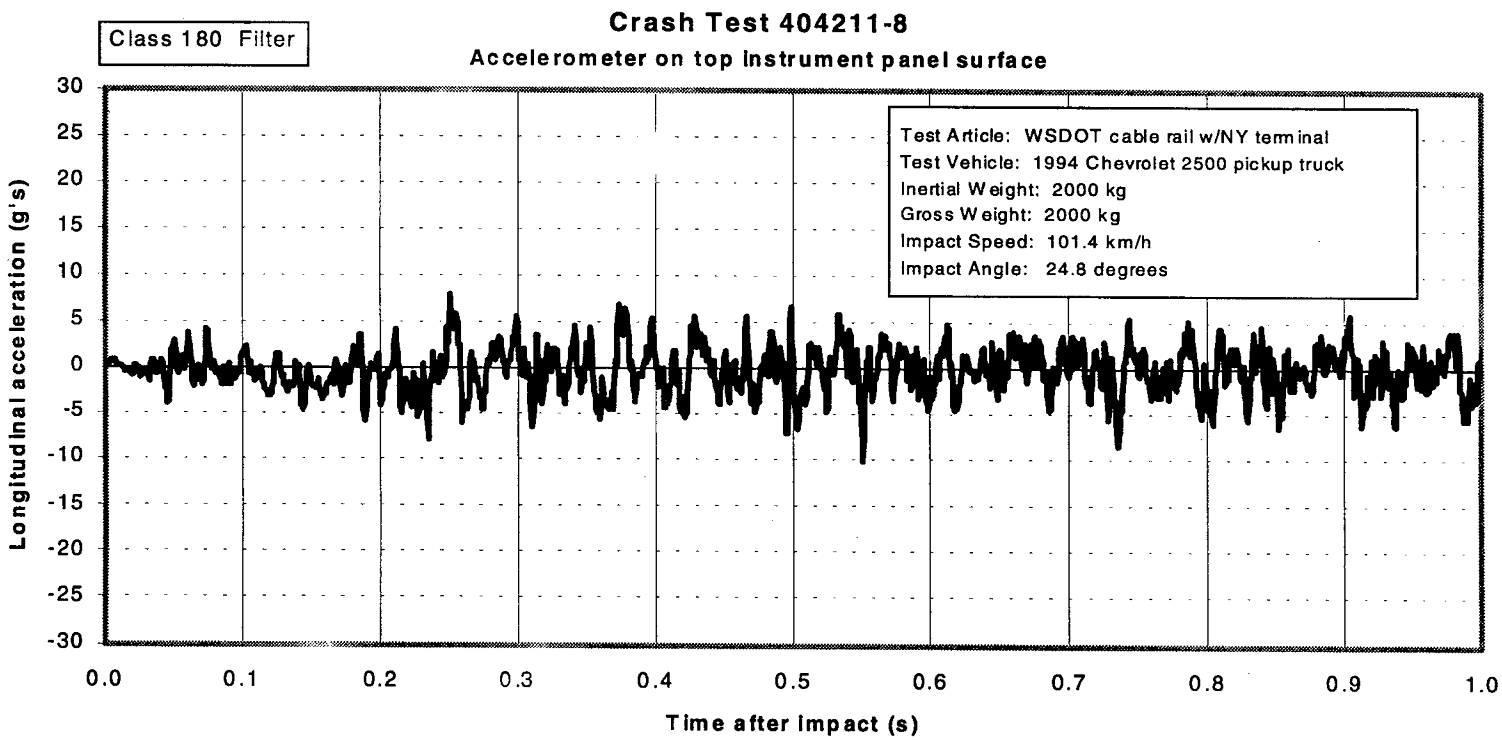


Figure 23. Vehicle longitudinal accelerometer trace for test 404211-8 (accelerometer located on top surface of instrument panel).

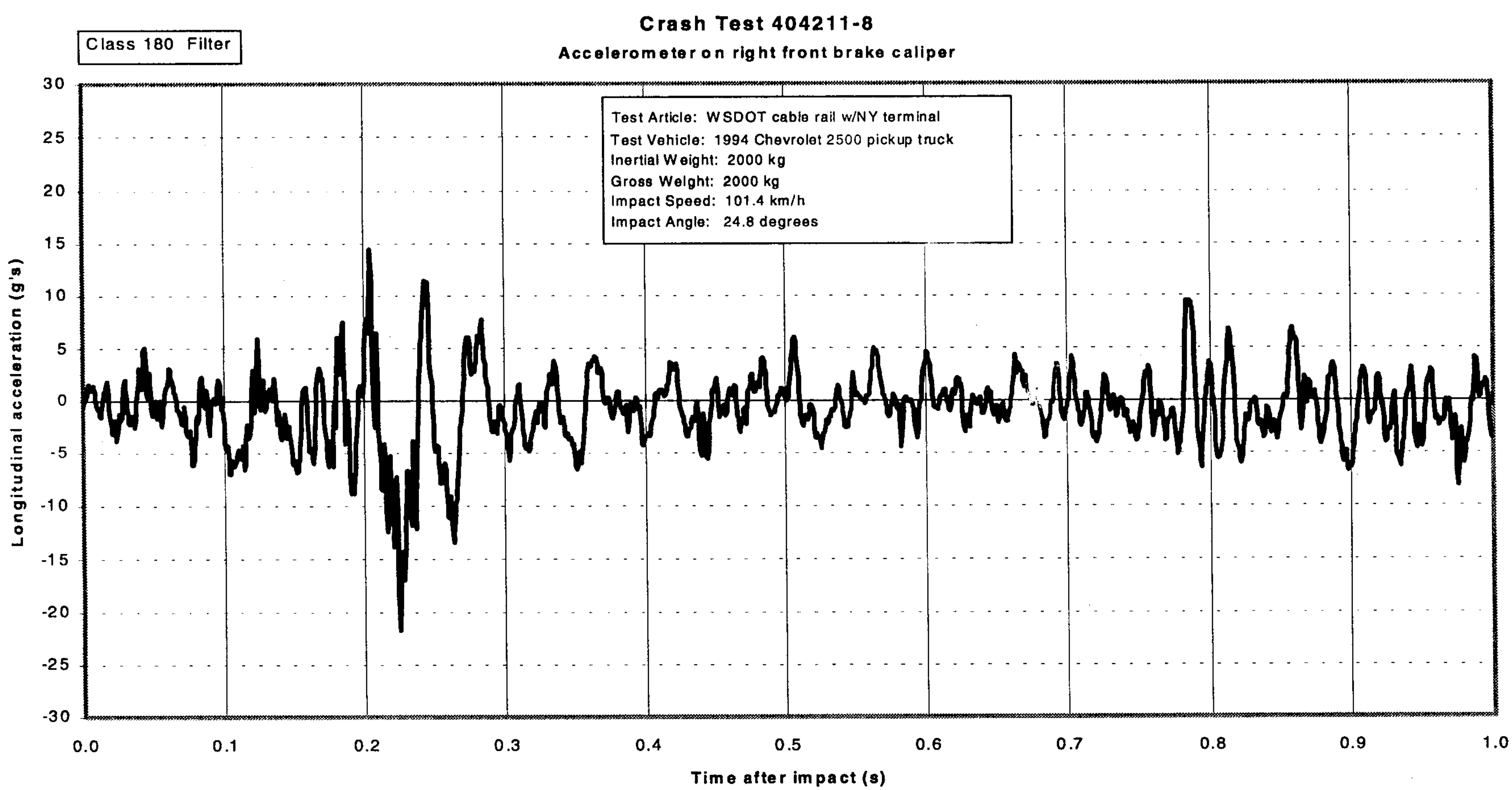


Figure 24. Vehicle longitudinal accelerometer trace for test 404211-8 (accelerometer located on right front brake caliper).

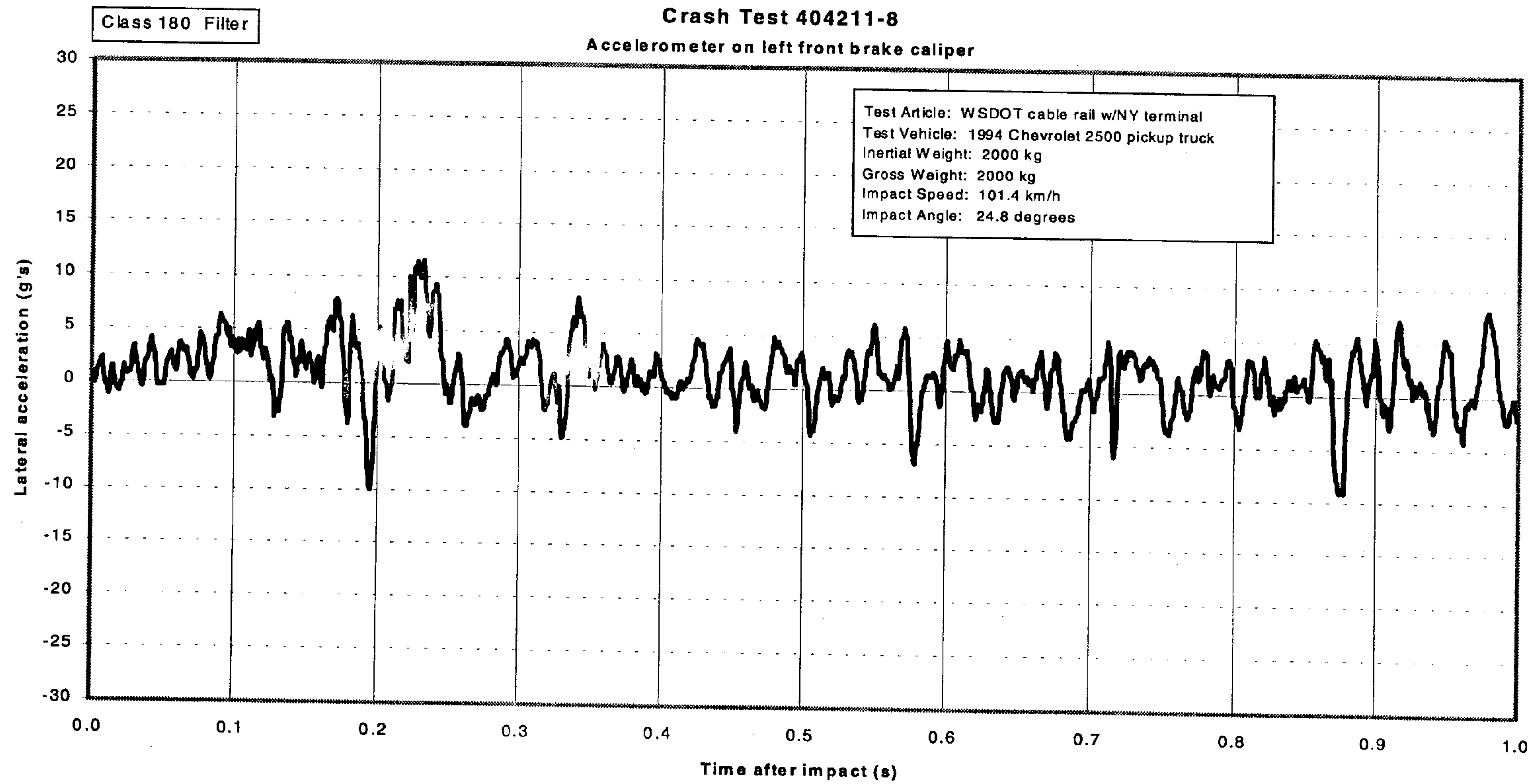


Figure 25. Vehicle longitudinal accelerometer trace for test 404211-8 (accelerometer located on left front brake caliper).

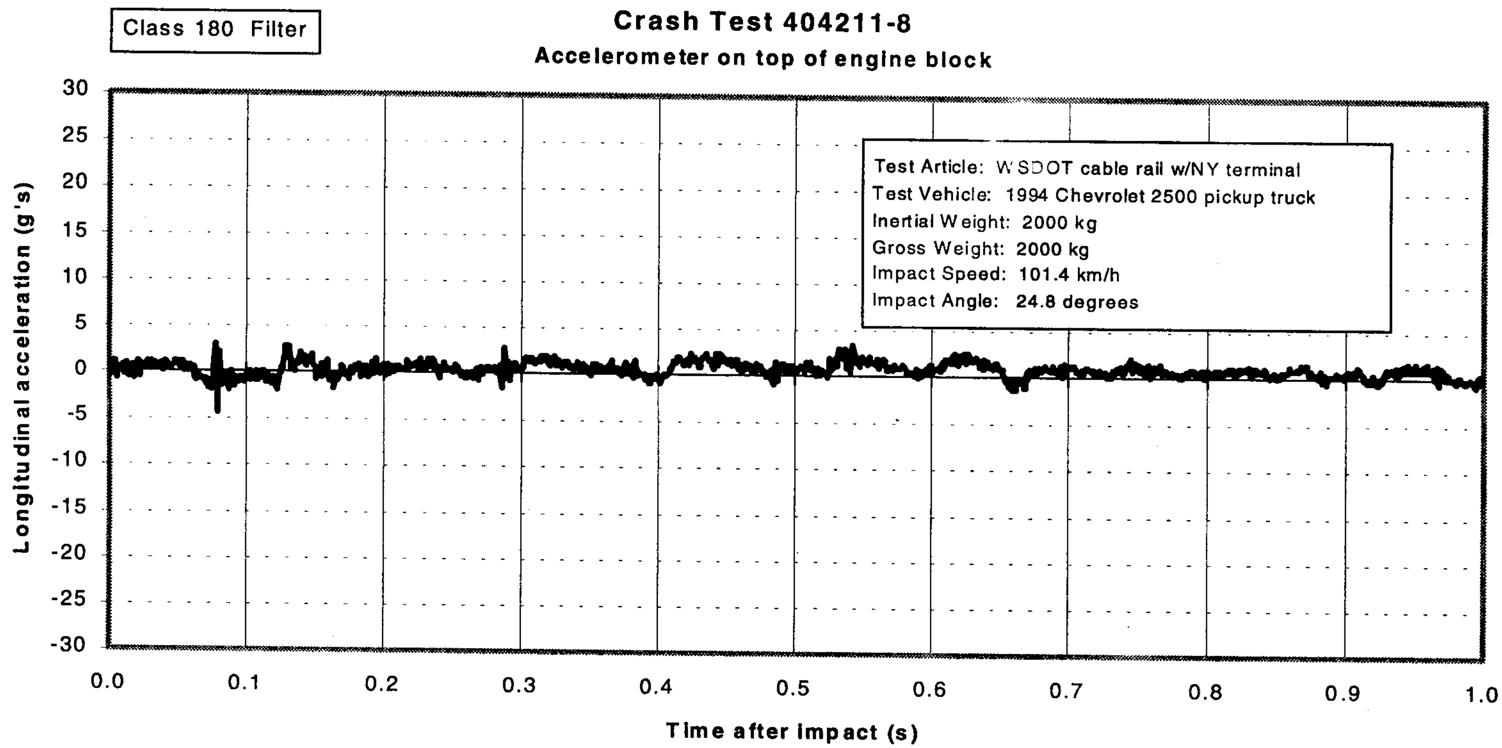


Figure 26. Vehicle longitudinal accelerometer trace for test 404211-8 (accelerometer located on top of engine block).

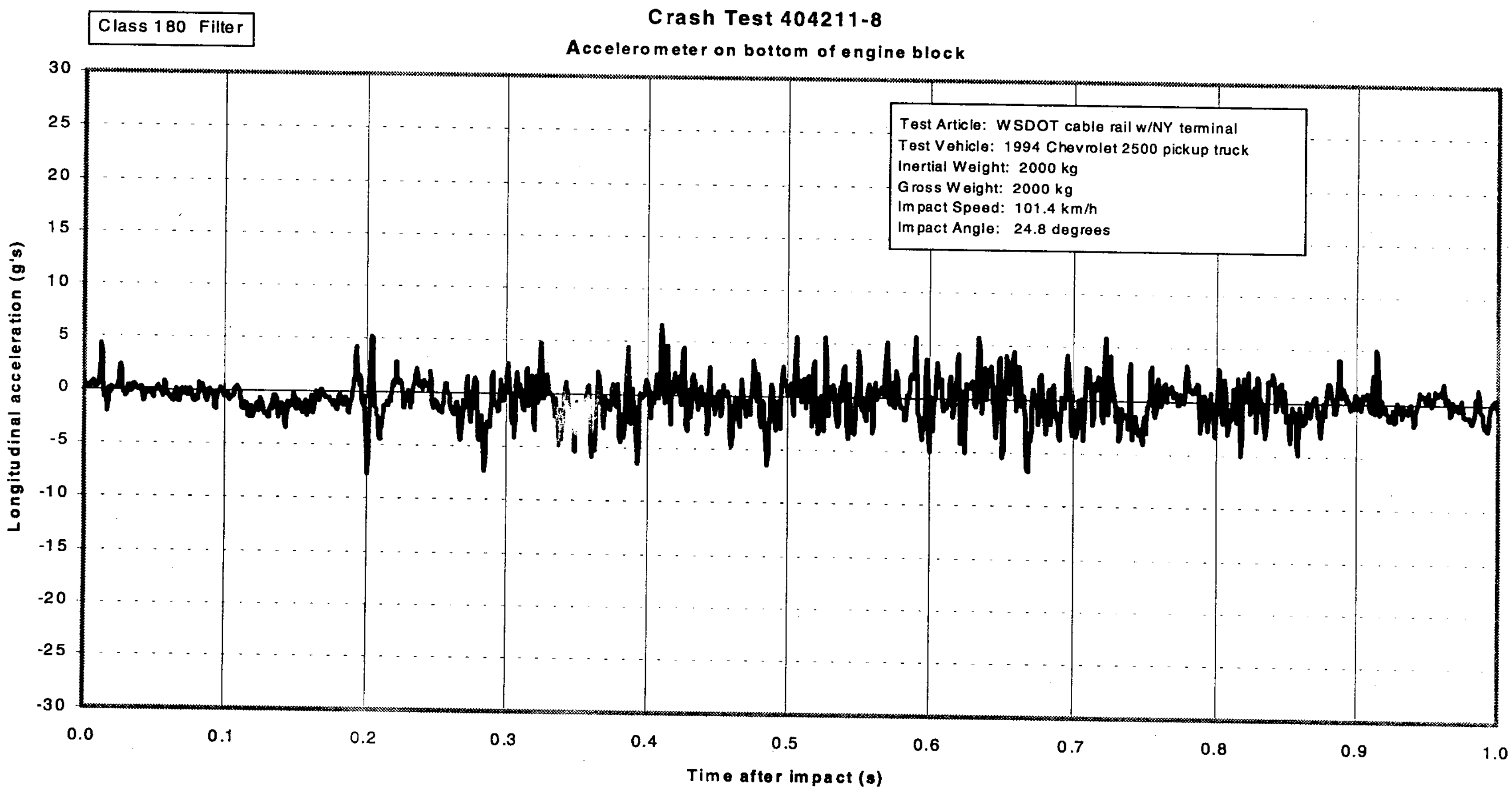


Figure 27. Vehicle longitudinal accelerometer trace for test 404211-8 (accelerometer located on bottom of engine block).

REFERENCES

1. H. E. Ross, Jr., D. L. Sicking, R. A. Zimmer, and J. D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.

2. D. Lance Bullard, Jr., and Wanda L. Menges, *Crash Testing and Evaluation of the WSDOT Three Strand Cable Rail System*, Research Report 270687-WDT2, prepared for Washington State Department of Transportation, Texas Transportation Institute, The Texas A&M University System, College Station, TX, June 1996.

3. C. Eugene Buth, Wanda L. Menges, and William F. Williams, *NCHRP Report 350 Test 3-34 of the New York Cable Rail Terminal*, Test Report 404211-6 prepared for Federal Highway Administration, Texas Transportation Institute, The Texas A&M University System, College Station, TX, October 1998.